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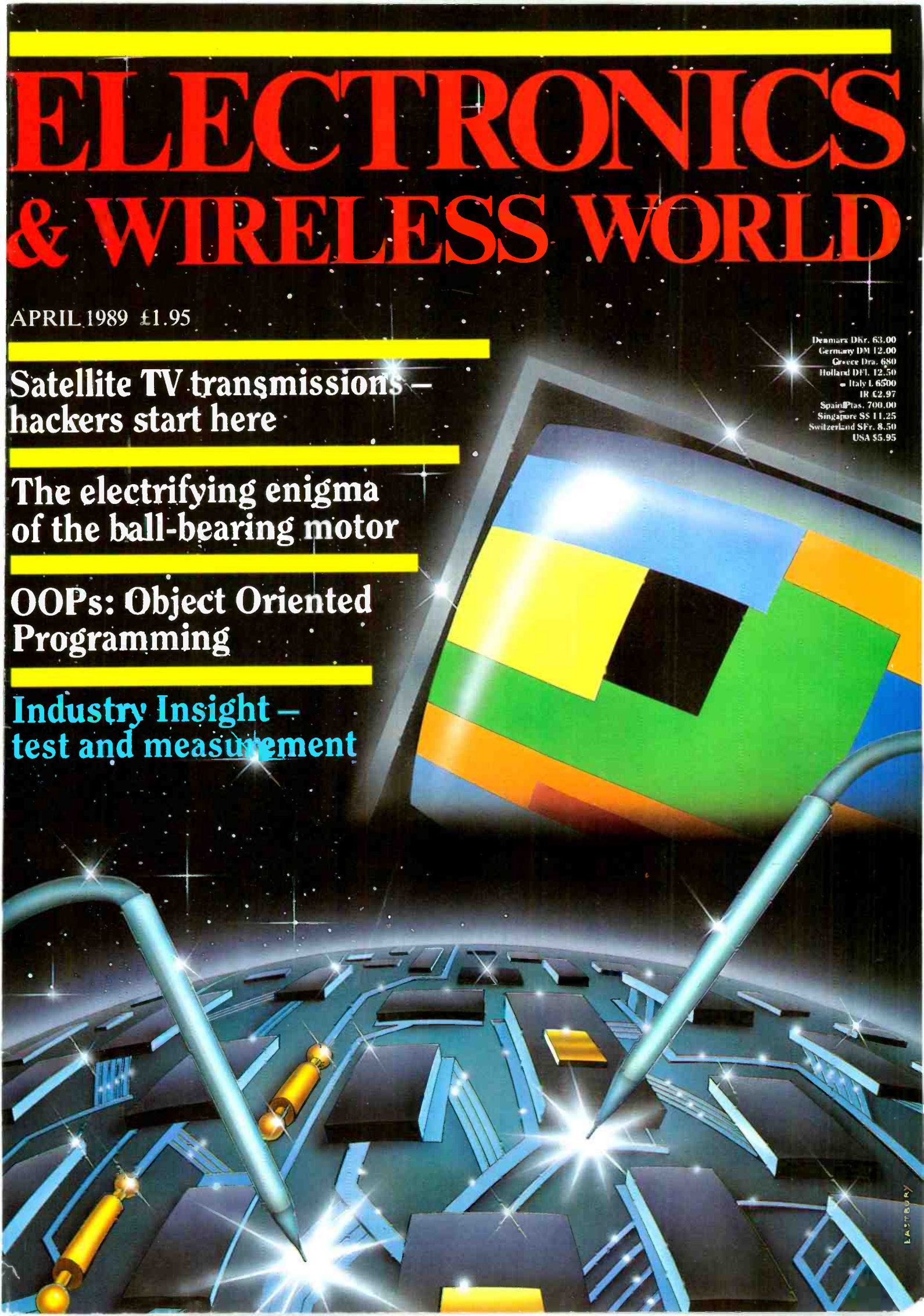

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1225	Logic Analyser, 100Hz 48-Channel	£ 1500
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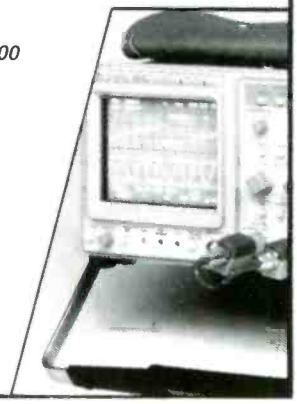
WILTRON

6663A	2 to 40GHz Sweep Generator	£17500



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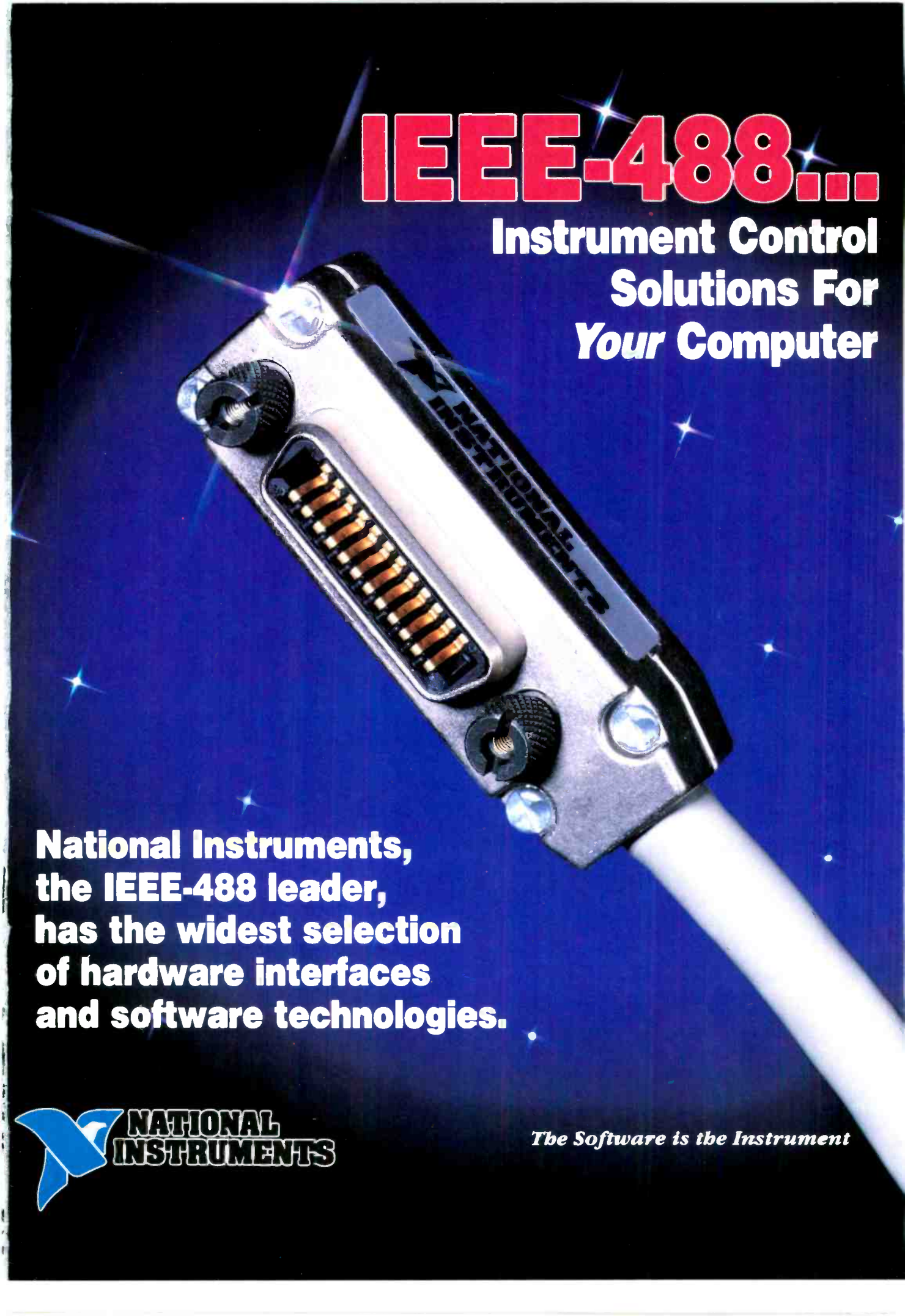
Instrument Control Solutions For *Your* Computer



National Instruments, the IEEE-488 leader, has the widest selection of hardware interfaces and software technologies.

NATIONAL INSTRUMENTS

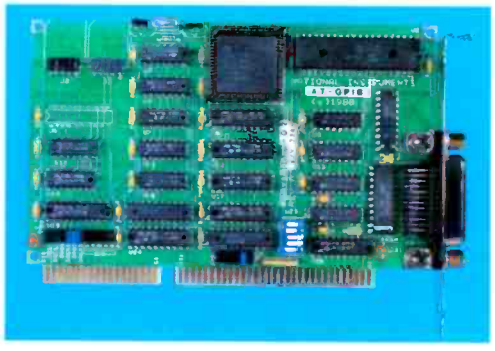
The Software is the Instrument

NATIONAL INSTRUMENTS HARDWARE MEETS ALL YOUR GPIB NEEDS

National Instruments has been working with the IEEE-488 bus (GPIB) for more than 12 years. Our hardware products are designed to meet *all* your needs. Choose any popular computer and we have an IEEE-488 solution. Each product line also offers you the choice of a low-cost solution for less demanding applications or a high-performance solution for applications that demand the best. We back our products with comprehensive customer support. No one gives you more choices, better performance, or better support than National Instruments.

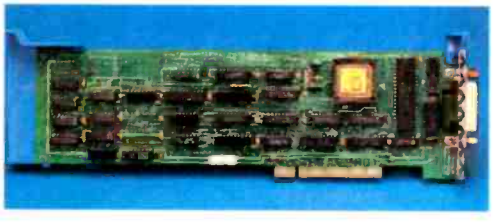
Turbo488™ ASIC Technology

At the heart of our highest performance interface boards is the National Instruments Turbo488 Application Specific Integrated Circuit (ASIC). Turbo488 integrates 26 chips into one, resulting in a lower cost implementation with significantly improved performance. Special last-byte handling significantly reduces the software overhead of an application program.



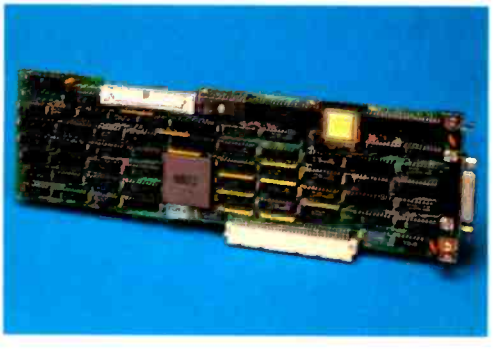
AT-GPIB—PC/AT Interface

- ★ Turbo488 ASIC
- ★ 1M bytes/sec DMA rates
- ★ GPIB monitor port for board and bus level diagnostics
- ★ Byte-to-word packing/unpacking to increase throughput
- ★ 11 interrupt levels
- ★ Three 16-bit DMA channels
- ★ Shared interrupt and DMA capability
- ★ LabWindows and NI-488 Software support
- ★ Operates independent of AT clock speed



MC-GPIB—Personal System/2 Micro Channel Interface

- ★ Turbo488 ASIC
- ★ 1M bytes/sec DMA rates
- ★ Programmable Option Set circuitry for selecting I/O address, interrupt level, and DMA channel
- ★ Byte-to-word packing/unpacking to increase throughput
- ★ LabWindows and NI-488 Software support



NB-DMA-8-G—Macintosh II NuBus Interface

- ★ Turbo488 ASIC
- ★ 1M bytes/sec DMA rates
- ★ 8 channels of high-performance 32-bit DMA
  - — Buffer chaining
  - — Accesses full NuBus 4 gigabyte address space
- ★ DMA and timing support for National Instruments data acquisition cards via RTSI bus
- ★ 8 independent 16-bit counter/timer channels
- ★ LabVIEW and NI-488 Software support

NB-GPIB—Macintosh II NuBus Interface

GPIB-SE—Macintosh SE Interface

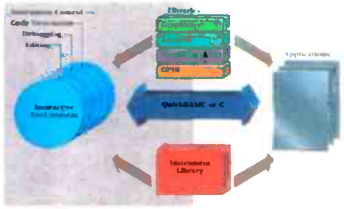
NB-GPIB

- ★ Turbo488 ASIC
- ★ 400K bytes/sec programmed I/O rates
- ★ GPIB monitor port
- ★ DMA operations over RTSI bus with NB-DMA-8-G
- ★ Byte-to-word packing/unpacking to increase throughput
- ★ LabVIEW and NI-488 Software support

GPIB-SE

- ★ Turbo488 ASIC
- ★ 1M bytes/sec rates with optional DMA controller
- ★ Optional numeric coprocessor
- ★ LabVIEW and NI-488 Software support

SECOND GENERATION



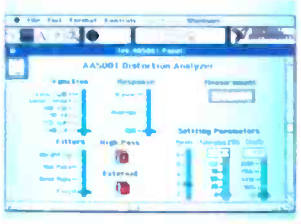
LabWindows®

LabWindows is a software system for the IBM PC, PS/2, and compatibles designed to provide rapid development, prototyping, and operation of test and measurement applications by fortifying and enhancing C and QuickBASIC. These languages are fortified by an interactive development environment and enhanced by supportive libraries. Instrument control applications can be quickly developed using LabWindows interactive editing and debugging features, automatic code generation mechanisms, instrument library, GPIB library, graphics library, analysis library, and formatting and I/O library.

Lotus Measure®

Lotus Measure is a set of data acquisition drivers for Lotus 1-2-3 or Symphony that can collect data and store it directly into a 1-2-3 or Symphony spreadsheet. Lotus Measure fortifies the 1-2-3 or Symphony macro command language by adding an advanced set of macro commands to perform IEEE-488, RS-232, and analog-to-digital operations. All functions available in the worksheet can be easily accessed for immediate reduction, analysis, and presentation of the data.

THIRD GENERATION



LabVIEW®

LabVIEW is an easy-to-use, powerful graphical programming language for the Macintosh family of computers. LabVIEW (Laboratory Virtual Instrument Engineering Workbench) has a complete integrated programming environment for applications involving instrument control, data acquisition, data analysis, data formatting, data presentation and data management. LabVIEW also has an extensive Instrument Library. The basis of LabVIEW is the representation of a software module as a Virtual Instrument. A Virtual Instrument is a real instrument made with software. LabVIEW users construct programs using block diagrams—a natural design notation of scientists and engineers. These block diagrams are the actual executable programs, that can be operated by way of user-defined graphical front panels that look and act like instruments.

Additional Application Software

National Instruments IEEE-488 interface boards are widely recognized for their quality and performance and are supported by many application software packages:

- ASYST
- GURU
- TestWindows
- ASYSTANT
- EZ-TEK
- LaserPaint
- TBASIC
- EZ-TEST
- SPD
- XScan
- WaveTest
- ChromaScan
- LABTECH NOTEBOOK
- Parameter Manager

Instrument Libraries

There exist over 4000 IEEE-488 compatible instruments manufactured by more than 300 vendors worldwide. Each of these instruments has its own, unique set of commands that make it function programmatically. The real ease of programming instruments comes from having a library of pre-packaged software modules that operate instruments, by way of intuitive, graphical panel interfaces. An instrument library makes operating an instrument from the computer as easy as operating it from its front panel. National Instruments is dedicated to increasing the instrument libraries of both LabWindows and LabVIEW by adding the instruments frequently requested.

NATIONAL INSTRUMENTS®
The Software is the Instrument™

Ordering Information
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Kingston upon Thames
KT1 1ER
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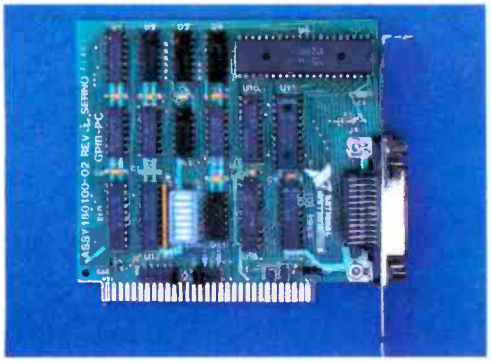


GPIB-PCII/IIA—IBM PC Interface

- ★ Half-size card
- ★ DMA rates over 300K bytes/sec
- ★ Standardized by IBM
- ★ AEGIS handler for Apollo 3000 and 4000 workstations
- ★ 6 interrupt lines
- ★ 3 DMA channels
- ★ LabWindows and NI-488 Software support

GPIB-PCIII—IBM PC/XT/RT PC Interface

- ★ Onboard high-speed FIFO buffer
- ★ 1M bytes/sec DMA rates
- ★ GPIB monitor port
- ★ Optional AIX handler
- ★ Interrupt circuitry for detecting SRQ and clock alarm
- ★ LabWindows and NI-488 Software support

MicroGPIB Products—Converters, Controllers, and Data Buffer

MicroGPIB Products

- ★ **GPIB-232CV** bidirectional transparent data converter between IEEE-488 and RS-232
- ★ **GPIB-422CV** bidirectional transparent data converter between IEEE-488 and RS-422
- ★ **GPIB-PRL** transparent parallel data converter
- ★ **GPIB-232CT** full-function IEEE-488 controller from RS-232 port
- ★ **GPIB-422CT** full-function IEEE-488 controller from RS-422 port compatible with Macintosh serial port
- ★ **GPIB-SCSI** full-function IEEE-488 controller from SCSI port
- ★ **GPIB-BUF** IEEE-488 data buffer with 900K bytes/sec transfer rates and 1M bytes of RAM

GPIB-MAC

- ★ Macintosh serial port interface
- ★ External configuration switches
- ★ 2K to 32K byte data buffer
- ★ Baud rates from 300 to 57.6K bits per second
- ★ LabVIEW Software system support

GPIB 100 Series—Bus Extenders/Expander

- ★ **GPIB-100A** High performance parallel bus extender
  - — Supports 28 devices at 300 m
  - — 222K bytes/sec transfer rates
- ★ **GPIB-110** Serial bus extender
  - — Fiber optic or coaxial cabling
  - — 144K bytes/sec transfer rates
- ★ **GPIB-120** Bus Expander
  - — Optically isolates 2 GPIB buses
  - — Extends GPIB by interfacing up to 14 more devices
  - — Doubles the GPIB 20 m cable limit
  - — Transparent to user software

GPIB-410—Bus Analyzer/Monitor

- ★ For use in debugging any GPIB application
- ★ Stores GPIB status in memory for later review
- ★ Simulated LEDs reflect the current condition of the GPIB
- ★ Emulate source or acceptor
- ★ Requires IBM PC as host

GPIB11 Series—Q-BUS/UNIBUS Interfaces

GPIB11V-2
- ★ Dual height card for Q-BUS
- ★ Supports MicroVAX series of computers
- ★ 250K bytes/sec DMA rates

GPIB11V-1
- ★ Dual height card for Q-BUS
- ★ 50K bytes/sec programmed I/O rates

GPIB11-2
- ★ Hex height card for UNIBUS
- ★ 500K bytes/sec DMA rates

GPIB11-1
- ★ Quad height card for UNIBUS
- ★ 60K bytes/sec programmed I/O rates

GPIB11 Series Software Support—RT, RSX, MicroVMS, VAXELN, UNIX, and RSX11M+ handlers in source code; NI DEC-Style Software

GPIB-1014 Series—VMEbus Interfaces

Complete Support for Sun Computers

GPIB-1014
- ★ 500K bytes/sec DMA rates
- ★ Full 24-bit addressing

GPIB-1014P
- ★ Single or double height front panels
- ★ 80K bytes/sec programmed I/O rates

GPIB-1014DP
- ★ Dual GPIB-1014P interfaces on one expansion slot

GPIB-S3/4
- ★ Kit for Sun-3 and Sun-4 workstations
- ★ Includes interface board, adapter bracket, internal cable, and software

GPIB-1014 Series Software Support—UNIX, real-time and multitasking handlers, NI-488 Software

GPIB-796 Series—MULTIBUS/SBX Interfaces

Complete Support for Apollo Computers

GPIB-796
- ★ 24-bit MULTIBUS addressing
- ★ 500K bytes/sec DMA rates
- ★ AEGIS handler for Apollo 3000 and 4000 workstations

GPIB-796P
- ★ 3 optional iSBX connectors
- ★ 50K bytes/sec programmed I/O rates

GPIB-SBX
- ★ Intel iSBX bus interface
- ★ Turns GPIB-796P into multiport interface
- ★ 250K bytes/sec DMA rates

GPIB-796 Series Software Support—UNIX, AEGIS, real-time, and multitasking handlers, NI-488 Software

GPIB-961P—STD Bus Interface

- ★ STD-Z80, -8085, -8088 compatible
- ★ 500K bytes/sec DMA rates
- ★ RS-232, counters, timers, digital I/O lines
- ★ NI-488 Software support

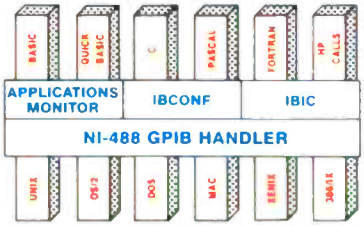
GPIB-3B2—AT&T 3B2 Interface

- ★ Onboard 80186 processor with 128K bytes of memory
- ★ 790K bytes/sec DMA rates
- ★ UNIX software
- ★ NI-488 Software support

THREE GENERATIONS OF SOFTWARE TECHNOLOGY

Three generations of innovative, high-performance software technology have been developed to simplify your programming task. The first generation includes flexible products that handle the fundamental I/O and data acquisition requirements. The second generation is an extension of the first generation that includes products that fortify and enhance an existing programming environment in order to minimize development time and meet the data acquisition, data analysis, and data presentation requirements. The third generation combines the features of the first two generations with an integrated programming environment and language designed for instrument control applications.

FIRST GENERATION



NI-488

NI-488 Software

The NI-488 software established a standard for PC-based instrument control drivers by introducing the first loadable IEEE-488 device driver for MS-DOS based personal computers. The NI-488 software now covers a number of different computer platforms such as IBM PC and PS/2, Macintosh, Sun, and Pro-Log STD-DOS. Major companies such as IBM, Tektronix, Philips, LeCroy, Howtek, Sharp, Perkin Elmer, Instron, Bruel & Kjaer, Hitachi Nakaworks, and Advantest all use the NI-488 software to produce innovative, high-quality products. This large backing has established NI-488 as the *de facto* **industry standard**.

Flexible

- Use any instrument, even one not 100% compatible with the IEEE-488 specification
- Use a language that meets the demands of your specific application (BASIC, C, Pascal, FORTRAN, Assembler)
- Use a computer architecture that will handle all your computing needs
- Use a multitasking operating system: versions for OS/2, UNIX, 386/ix, and XENIX

High-speed

- Designed to be a high-speed device driver
- Subroutine-based structure as opposed to a slower character I/O implementation
- Direct Memory Access (DMA) transfers are used without special programming instructions

Easy-to-use

- Subroutines and functions can be called from familiar programming languages
- Only a small number of high-level functions are needed for most applications
- To initialize the bus and configure a multimeter only two simple commands are needed:

Reliable

- Over twelve years experience developing GPIB device handlers
- Built-in error checking
- Exhaustive testing prior to release
- Quick response to user needs and suggestions

Utilities:

IBIC—With the IEEE-488 Bus Interactive Control (IBIC) utility you can control and communicate with instruments from the keyboard. The IBIC utility is a simple way to learn the NI-488 handler functions and the device-specific commands of the instrument or to troubleshoot the system.

Applications Monitor—A utility that performs automatic error detection and identification. For ease in debugging, a Session Summary of all the GPIB commands made during a session is generated.

IBCONF—A utility program that configures the NI-488 handler for GPIB addresses, timeout settings, termination methods, and device-specific characteristics.

HP-Style Calls—For users familiar with the calls supported by a Hewlett-Packard controller, the NI-488 software has an option for HP-Style function calls.

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Rupert Baines

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This article highlights the advantages of specific high level languages as applied to realtime control. By Brian Frost

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Changing role of digital oscilloscopes. We chart the rise and rise of this ubiquitous instrument. **389**

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Waferscale testing procedures. Can faulty circuitry be reclaimed by pouring in redundancy? The answer is probably yes, provided redundancy is backed with on chip intelligence. By Ivor Catt. **401**

Beyond modularity and automation. More recent architectures such as VXI and RTSI provide for precise timing at system level. But the software should be able to keep time from the top down. **403**

Computer-guided driving could soon be a reality – see Update p 336.

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Sigurd Varian never lost faith that, one day, his brother Russell "would invent the big one". He wasn't disappointed. The thing originally referred to by the Varian brothers as the "spittoon" was renamed the "klystron"

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A three-month community VHF experiment licensed by the DTI could pave the way for nationwide community broadcasting.

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MAKING ELECTRONICS C.A.D. AFFORDABLE

TINY-PC — PCB CAD, FOR THE PC/XT/AT — EASY-PC

- Are you still using tapes and a light box?
- Have you been putting off buying PCB CAD software?
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- Would you like to be able to produce PCB layouts up to 17" square?
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- Plus drill template and solder resist?
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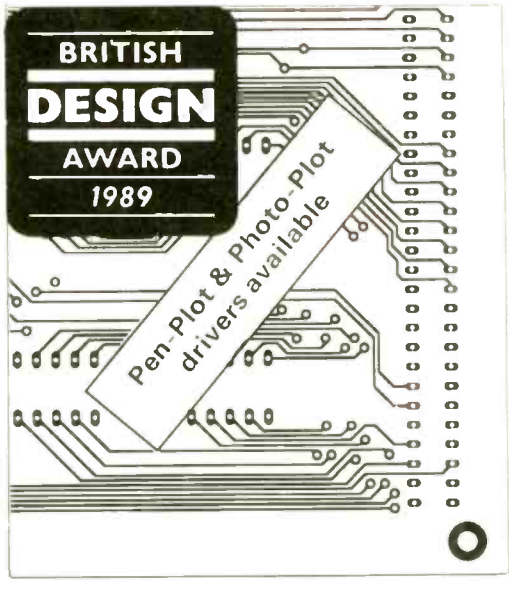
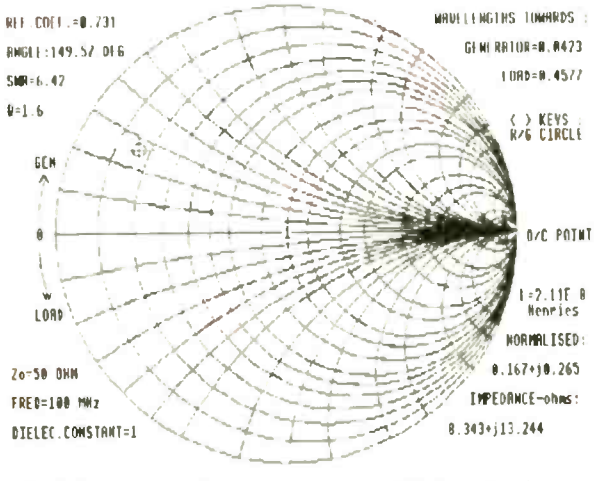
- That can be used with either cursor keys or mouse?
- That is as good at circuit diagrams as it is at PCB's?
- That outputs to Dot Matrix Printer, or, with extra drivers can drive a pen plotter or photoplotter.
- Where you can learn how to use it in around an hour?
- **THAT ONLY COSTS £95+VAT (TINY-PC), £275+VAT (EASY-PC)**



Output on dot matrix printer reduced from 2:1

SMITH CHART PROGRAM — Z MATCH

For IBM, PC/XT/AT and clones inc. Amstrad 1512 and 1640 and BBC B, B+ and Master.



Z-MATCH – Takes the drudgery out of R.F. matching problems. Includes many more features than the standard Smith Chart.

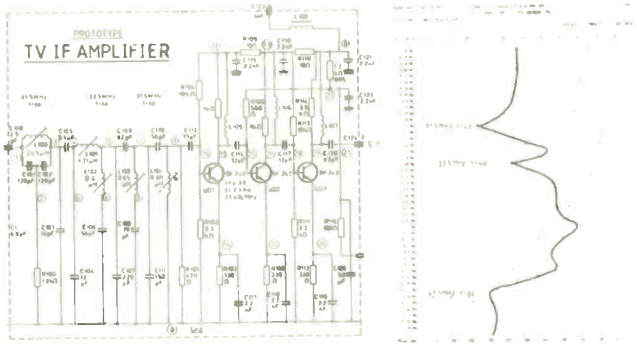
Provides solutions to problems such as TRANSMISSION LINE MATCHING for AERIALS and RF AMPLIFIERS with TRANSMISSION LINE, TRANSFORMER and STUB MATCHING methods using COAXIAL LINES MICROSTRIP, STRIPLINE and WAVEGUIDES.
The program takes account of TRANSMISSION LINE LOSS, DIELECTRIC CONSTANT, VELOCITY FACTOR and FREQUENCY.

Z-MATCH is supplied with a COMPREHENSIVE USER MANUAL which contains a range of WORKED EXAMPLES

£130 for PC/XT/AT etc.
£65.00 for BBC B, B+ and Master

CIRCUIT ANALYSIS BY COMPUTER — ANALYSER II

For IBM PC/XT/AT and clones inc. Amstrad 1512, 1640, R.M. NIMBUS, and BBC B, B+, and Master.



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An old prejudice

Attend any convention of electronics engineers and you will find that the delegate sitting next you is more than likely to be a man. Indeed, the entire row of seats in which you are sitting will probably be occupied by men. In an audience of 100, perhaps half a dozen delegates will be women. This appears to be blatant prejudice on the part of the electronics industry, a state of affairs which wouldn't be allowed to continue elsewhere in society.

Our industry has responded with rather self-conscious initiatives along the lines of 'Woman Engineer/Designer/Technician of the Year' – very worthy, but totally missing the point. This journal has never encountered a direct case of discrimination against women. Discrimination, if this is the right word for it, occurs with the individual's first encounter with the education system. Boys are encouraged to play with computers and electronics; girls aren't. The association is ingrained at an early age, reinforced by a predominantly female primary-school teaching corps with a similarly limited outlook.

This damaging attitude of mind can best be resolved by education secretary Kenneth Baker. Given that we could be wasting nearly half of the country's latent talent, we look to him for speedy action. Yet the electronics industry harbours another form of blatant discrimination which it could do something about itself: ageism.

'Ageism' is a concocted word, but nonetheless apt, and implies a totally negative attitude to the acquired experience, proven performance and reliability often found in older people. The following letter was received at the offices of our sister publication *Electronics Weekly*.

> "Once you turn 45 it is difficult to obtain re-employment in the electronics industry. This is the conclusion I have reached as a 56-year-old quality manager of some 20 years experience.
>
> "I have worked all the way through engineering from the bench right through to divisional quality manager for a large company. In the last nine to twelve months I have been trying to obtain a new position, but constantly get turned down. Out of some 30-odd applications, I have been granted only one interview."

One can't definitely state that the writer of this letter and the hundreds of people like him will turn out to be the perfect employee for any given job; but neither can one be any more certain of a new recruit to the industry. It seems odd that companies prize youth well above proven experience. It appears even stranger in the light of an industry professing to suffer a skills shortage.

A youthful outlook certainly helps in circumstances where preconceptions and habits could be limiting. Marketing jobs involve a ready acceptance of risk; the caution which comes from bitter experience may well be inhibiting. Most other jobs which spring to mind would seem to benefit from experience, however. In short, individual qualities could be more important than the candidate's age. It is thus unfair, wasteful and inappropriate to pursue ageism.

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RESEARCH NOTES

Superconducting dipoles

One of the world's first practical applications for high-temperature superconductors is a miniature dipole antenna developed at the University of Birmingham. Michael Mehler of the Department of Electronic and Electrical Engineering has demonstrated in the laboratory an efficient dipole constructed from yttrium barium copper oxide ceramic material (YBa_2Cu_3Ox) and operating at liquid nitrogen temperatures (77K).

Two obvious questions arise: why use superconductors when losses in conventional antennas aren't usually great and what's the practical value of an antenna if it has to be immersed in liquid?

The answers to both these questions have to do with size. There are many situations in which a full-size HF dipole, for example, would be out of place. Anything larger than a few tens of centimetres long would be difficult to accommodate on a fighter aircraft or a spacecraft during its passage through the atmosphere. Scaling down a standard half-wave dipole or loop antenna to around a tenth of its normal size would thus be extremely advantageous.

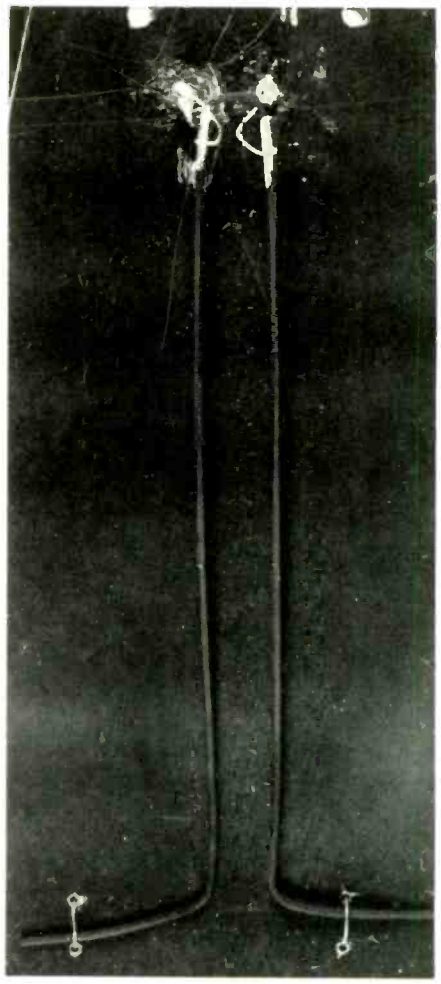
Obviously it is not impossible to get such a miniature antenna to radiate, though the losses under normal circumstances would be extremely large. Not only would the dipole impedance be very low (~0.1Ω) it would have a large reactive component. Matching would be difficult and losses, even in a copper radiating element, would be high.

Attempts to circumvent resistive losses have been made in the past using conventional metallic superconductors operating at about 4K in liquid helium. Such attempts, though successful, have been unpractical and prohibitively expensive for everyday applications.

By using the new ceramic superconductors Mehler has, in effect, turned a bit of esoteric engineering into something with practical potential. What he's done is to fabricate a 550MHz dipole a mere 20mm long and its associated matching network and line, all from the new ceramic material. Surrounded by a glass dewar containing liquid nitrogen, the whole tiny assembly matches a 50Ω source and radiates just as well as a full-size copper dipole.

As far as practicalities go, the ceramic dipole is connected to its RF source by means of wire-wrapping and silver paint, no real problem. Nor is the refrigerant. Apart from being transparent to radiated RF well into the gigahertz region, liquid nitrogen is cheap and readily available.

With backing from the Science and Engineering Research Council (SERC) and the Ministry of Defence, Michael Mehler is now refining the hardware and also developing other practical configurations such as loops and multi-element arrays.



Quarter micron c-mos developed at IBM

A milestone in the race for ever smaller and hence more powerful memories was contained in a paper presented at the 1988 International Electron Devices Meeting in San Francisco by a team of researchers from IBM's Yorktown Heights Laboratory. B. Davari *et al.* report success in the construction of c-mos circuitry using transistors only 0.25 micron wide (250nm). Such tiny elements, they say, would make possible c-mos memory chips with a capacity of 256 megabits.

The IBM circuits were fabricated in bulk silicon technology using advanced optical lithography, incorporating elements that are only 7mm, that is 20 atomic layers thick. These quarter-micron circuits are the smallest that have so far been incorporated in c-mos though the team have now made experimental tenth-micron n-mos devices which they hope to develop in the same way.

Research Notes is written by John Wilson of the BBC World Service science unit.

Amps, volts and bananas. . .

For decades now we've had electronic transducers that will convert most physical quantities into their electrical analogues. Temperature, pressure, light intensity, mass and nuclear radiation are just a few examples of quantities that are easily measurable with cheap and readily available transducers.

More recently, this list has begun to include detectors for chemical entities such as hydrocarbons, smoke particles, alcohol etc. But imagine the range of uses for a transducer that could generate an electrical output directly proportional to the concentration of AIDS virus. . . .

So far, the development of entity-specific sensors has proceeded very slowly indeed for a number of reasons, some practical and some to do with the chemical reactions on which they depend. The most obvious approach of coating a chemical reagent directly on to a silicon circuit element has proved disappointing because of corrosion or other interactions between the two.

Two interesting new approaches are, however, proving more successful. George Guilbault, a chemistry professor at New Orleans University is one of a number of researchers who are experimenting with monoclonal antibodies coated on piezo-electric transducers. Monoclonal antibodies, developed originally in Cambridge, are highly specific reagents that will bind chemically to individual complex chemicals. Thus it is possible to create a monoclonal antibody that will react only with one particular protein. When such an antibody is coated on a piezo-electric crystal the resonant frequency is critically determined by its mass. So if a protein comes along that binds to the antibody the mass will increase and the resonant frequency will decrease. Guilbault has so far employed such a system to make electronic detectors that are specific for cocaine and for various agricultural pesticides.

RESEARCH NOTES

The deafening smell of pollution

We've all by now grown used to the idea that excessive noise can cause deafness. Above a certain threshold it is very nearly a product of amplitude and duration. But of all the factors likely to induce hearing loss, airborne pollution hasn't up till now been a front runner.

Disturbing experiments conducted at Johns Hopkins University in the USA and at two Japanese institutions show that, in rats, noise and atmospheric carbon monoxide levels have an additive effect. Laurence Fechter, Associate Professor of Environmental Health Sciences, has produced data to show that the danger threshold level for noise is considerably lowered in the presence of carbon monoxide. Moreover, noise levels and carbon monoxide concentrations (500ppm), harmless on their own, can cause permanent ear damage when combined.

Although there's no direct means of proving that the same is true for humans, Fechter is convinced that the risk is a very real one. This is especially so in view of the tendency of high ambient noise levels to occur in the same situations as high carbon monoxide levels. Examples that come to mind include smokers in discos, furnace operators and transport workers. Smokers have carbon monoxide levels in their lungs of around 350ppm — not much below the level that causes serious problems for rats.

Providing conclusive proof of a risk to human health will not of course be easy. But if it does emerge, it will be immensely complicating for occupational health legislators. No longer will it be reasonable, for example, to specify blanket intensity/time limits on noise in all environments. And of course the famous orange warning light, bane of concert promoters, could well in future need to have a second input . . . from a gas detector.

Viruses wait for All Fools' Day

Stories about computer viruses make curiously compulsive reading. Could it be that they appeal to our gruesome appetite for disaster? Or is it because such stories reveal that machines, like men, have feet of clay?

As a lifelong joker with natural sympathies for the under-dog I must confess to finding more than a little entertainment value in some recent reports... like the innocuous little program that was designed to deposit a mere 400 bytes of garbage in a memory on the day its hapless investigator was removed from the company payroll. Each successive day the garbage was programmed to double until... calculators at the ready... it jammed up a whole 300 megabyte memory in a little under three weeks.

Or what about a virus, dubbed Sizzle, that somehow managed progressively to increase the clock rate of its host until the central processor became incandescent from the thermal dissipation? Ingenious at least.

Now, as April 1st approaches, academic institutions all over the country are bracing themselves for a repeat of some clone of the '1813 Friday the Thirteenth Virus' that struck in January. According to a number of London consultants this is more than just speculation: threats have already been received.

One answer of course is to equip yourself with one of the many anti-viral programs or vaccines that are now appearing on the market. "Immunise" is just one example of this increasingly anthropomorphic breed. But are these medical allusions merely marketing hype or journalistic licence? Or could it be, as I hinted earlier, that machines and men are actually evolving, along convergent lines?

If so, may I leave you to ponder a sobering thought... what happens when someone writes a rogue program called Computer Immunodeficiency Virus (CIV)? Please send your suggestions under plain wrapper... and of course make sure they're electronically tested.

Another intriguing approach to biochemical sensing goes one stage beyond the use of biologically active substances. Garry Rechnitz of the University of Delaware is using bits of living creatures built into electrodes. In particular he's fitted lead-out wires to the antennae of blue crabs. When immersed in water the crab antennae act more-or-less as ready-made transducers, producing electrical nerve impulses in direct proportion to the concentration of certain toxic pollutants.

Plants, too, can be pressed into service as chemical sensors. Rechnitz has used an oxygen-sensing electrode in conjunction with a slice of banana to detect an important brain chemical called dopamine. This 'bananatrode', as he calls it, produces an electrical signal that could, in theory at least, measure susceptibility to Parkinson's disease (due essentially to lack of dopamine).

Some of these experimental devices may seem somewhat whimsical, but there's a huge range of important applications awaiting biochemical sensors that are stable, reliable and resistant to the corrosive environment of the human body. Imagine, for example, a cure for diabetes in which an insulin pump were directly controlled by a feedback loop attached to a continuous-reading glucose sensor inside an artery.

Blind to our future?

At a recent press conference to launch their new book 'Pathways to the Universe', the Astronomer Royal Sir Francis Graham-Smith and Sir Bernard Lovell drew attention to an unseen form of pollution that has steadily been restricting our view of the Universe. That pollution is of course man-made radiation, not just at radio and optical wavelengths but across the whole electromagnetic spectrum including gamma rays.

The reason this problem has now reached critical proportions is twofold: first the increase in man-made radiation levels and secondly the increasingly distant and hence weak sources of natural radiation that are now, with the help of modern technology, capable of being observed. Such sources, often at the extreme edge of the observable Universe, are of particular interest because of what they can tell us about the early history of creation.

Pulsars and quasars, to say nothing of supernova explosions, represent some of the most fascinating and energetic regions of the sky – objects which, because of their energy, tend to emit in the shorter wavelength parts of the electromagnetic spectrum, mainly X-rays and γ-rays. Such rays do not penetrate the atmosphere and it's only in the last decade or so that this window on the Universe has been opened to astronomers by means of space-borne telescopes.

Yet this window, so recently opened, may soon close, according to Smith and Lovell. Soviet RORSAT military satellites carry unshielded nuclear reactors which emit γ-rays in far greater quantity than those arriving from the depths of space.

Radio astronomy, long a victim of man-made radiation, is now becoming more restricted than ever. No longer is it just occasional leakage from faulty equipment or drifting oscillators. Today the internationally agreed 'silent' bands allocated to radio astronomy are fast being invaded deliberately by such sources as military navigation systems.

All in all, our greed for spectrum seems set to deny researchers access to the information that would do most to answer the most fundamental of all questions about the origin and destiny of the Universe.

Making waves with electrons

The colour image which appeared under this title on page 114 of the February issue showed a tantalum disulphide charge density wave, and was kindly provided by Dr John Clarke of the physics department of the University of California at Berkeley. Further details of this work by Dr Clarke and his collaborators, led by Dr R. E. Thomson, appeared in *Physical Review B*, November 15, 1988.

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Low pressures create giant LCDs

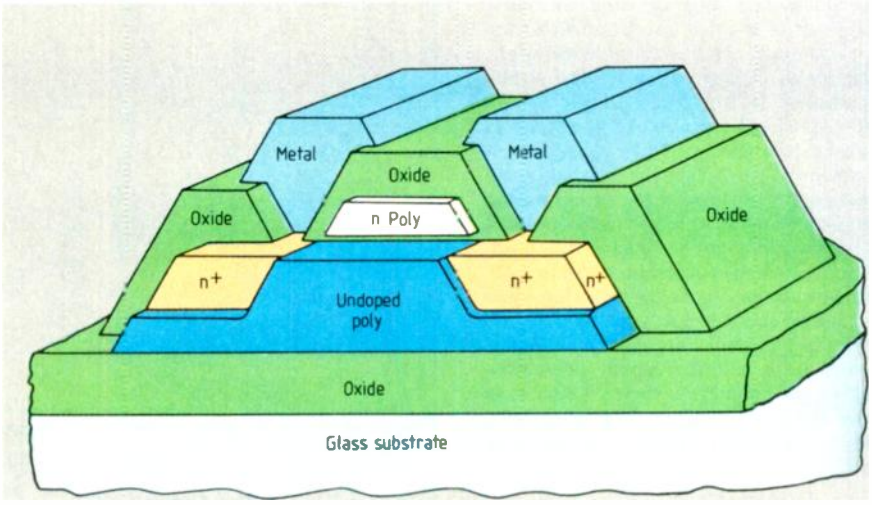
Imagine an A4 sheet of silicon upon which you can build translucent fet devices of good quality. Because the light will shine through, you could harness the photosensitive properties of the transistors for direct imaging on this enormous silicon target. Alternatively, packed into hermetic plastic, an A4 piece of silicon would produce a real monster of a chip. It becomes possible to implement neutral networks, parallel processing and memory without ever having to leave the wafer.

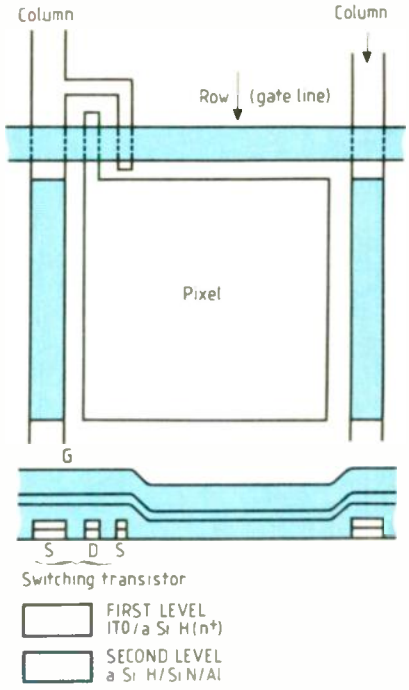
The idea of placing polysilicon on glass isn't new; semiconductor companies have repeatedly experimented with alternative substrates. Monocrystalline silicon produces devices with highly repeatable and excellent electronic properties. Because electrons can move freely about the silicon lattice, mobility is very high and the conducting state resistance accordingly low. Monocrystalline silicon also has the inherent advantage of the excellent surface smoothness necessary for repeatable submicron geometries. When you try to place silicon on glass by a chemical decomposition of gases such as silicon hydride, the silicon deposits as regular, small crystals or even takes an amorphous form. This is because the glass substrate interferes with the formation of the crystalline lattice. The resulting fractures in the silicon structure drastically reduce mobility within the polysilicon layer.

Display manufacturers in Japan have produced LCD display products for the commercial market up to around 35cm diagonal size which use amorphous silicon. However, the very high resistance of the amorphous silicon pixel-switching transistors means that the display is very slow to refresh. The new polysilicon on glass substrate technology from Rytrak promises high quality silicon display screens up to 35cm with acceptable refresh rates.

There isn't anything spectactularly new in the Rytrak CVD (chemical vapour deposition) process. It does little more than carefully control the deposition pressure and the accompanying thermal gradient within the deposition chamber. The manufacturing principle is straightforward. The processes exposes high purity glass to SiH_4 gas at a temperature of around 600°C. The gas decomposes to form a layer of silicon on the glass sheet. Traditionally this process would involve a chamber pressure of around 200mtorr. This results in a silicon deposition rate in the region of 100A per minute requiring a total process time of around 10 minutes to an hour to reach the desired silicon thickness. This type of silicon is characterized by very small crystals of relatively poor electrical performance for the intended application. As a first pass at solving the problem Rytrak reduced the pressure to around 40mtorr resulting in a much better crystal structure but with a deposition rate which fell to 10A per minute, insufficient for a commercial process. It is thus very surprising to learn that the secret of the new CVD process is to reduce the process gas pressure to just 2mtorr, a reduction of two orders of magnitude from the traditional industry norm. One would expect the deposition rate at this very low pressure to be virtually zero but indeed the opposite appears to happen. The deposition rate actually rises to around 50-70A per minute, a figure compatible with a commercial process. It comes as an even bigger surprise that Rytrak does not know why this should occur.

One can speculate on why the massive pressure reduction should lead to an increase in deposition rate. The traditional CVD process has much lower gas flow rates even though the pressure is much higher. Whatever the reason, the company expects to delivery its first 35cm in substrates by the time you are reading this, and it seems assured of a bright future providing it can protect its patented process from the giant industry predators.



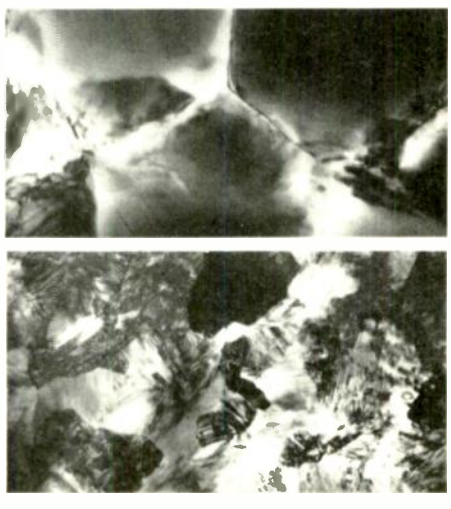


Above: three dimensional representation of a fet-on-glass structure.

Right: a pixel from a thin film transistor display uses essentially the same structure as dynamic memory. The transistor in the top left of the structure switches the capacitance of the pixel element.

Upper photograph: a cross-section of a polysilicon-on-glass film produced with a standard CVD process at 200mtorr process pressure. Note the fine grain of the crystals leading to high surface resistance.

Bottom right: a cross-section of polysilicon film deposited at 2.5mtorr using the Rytrak process. It clearly demonstrates that ultra low pressure CVD produces crystals of very large size and almost perfect uniformity.



Research profile: transport and road research

Martin Eccles

Department of Transport research into all aspects of Britain's highways and vehicles is carried out at the Transport and Road Research Laboratory in Crowthorne, Berkshire.

Electronics is responsible for two significant advances in traffic-flow efficiency – we could be feeling the effects of both of them in the near future. One is an interactive computer system called Autoguide that can guide drivers effortlessly to their destination and the other a traffic-light controller called Mova. A new traffic-light controller might seem unexciting to you until you learn that the ones currently used have been based on the same principles for about 50 years.

Surprisingly, one of the most electronics-intensive areas at TRRL is setting safety standards for the country's vehicles. Crash tests involve the use of many types of sensors, analogue and digital processors, and data recorders.

Inefficient traffic routing is thought to cost the nation £2400 million a year. According to TRRL, that represents some 6% of all vehicle mileage. This photograph is a demonstration of TRRL's Autoguide system that could save not only fuel and road wear, but also some 12% of driving time.

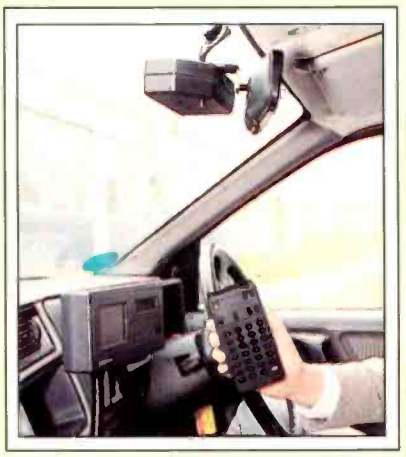
Unlike earlier attempts to route traffic efficiently, which include Prestel software and in-vehicle route-planning experiments, Autoguide looks promising. Some 15 cars in London are already equipped with Siemens Autoguide hardware as part of a practical evaluation and a number of consortiums including companies such as Plessey, Rover, the AA and Ferranti are interested in bidding for a pilot scheme which will provide London with some 300 information transmitting beacons and some 400 Autoguide equipped vehicles.

This demonstration illustrated to us Autoguide's ingenious ability to determine, rather than simply look up, the best route. If roadside beacons detect that drivers are taking longer than predicted to negotiate a particular route, Autoguide assumes that there is a delay on that route and gives subsequent drivers a modified route. Should, say, an accident have occurred on a particular route, beacon control centres can also insert route-modifying data into the beacon-control computer.

We are assured that although Autoguide knows whether Autoguide-equipped vehicles passing its beacons are *bona fide* users, it will not inform the police when a driver takes less than the predicted time to cover a given route!

Within the car are five main units relating to Autoguide, one of which is the display panel shown here. Besides verifying the destination that you have entered, the display panel gives directions – turn left, follow the road, etc. – and it even helps you when you are confronted with two or three left turns very close to each other. Looking at a display distracts the driver's attention and so each direction change is also announced by a voice synthesizer.

Information arrives at this display unit from infra-red beacons at strategic positions on the roadside with a range of about 50m. In central urban areas, it should be possible to direct drivers to within 50m of their destination.

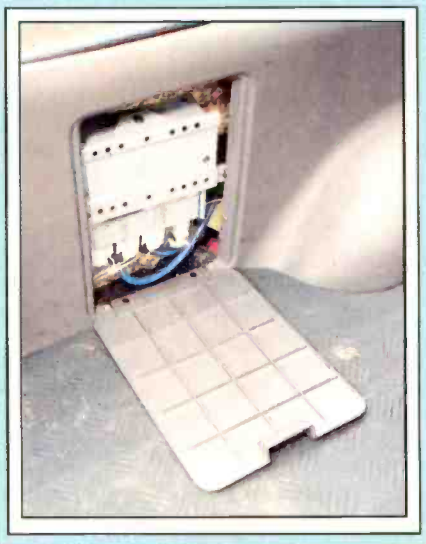


Roadside beacons transmit routing information continuously at 125kbit/s through an infra-red link; information travels from the car to the beacon too, but more slowly. Just behind the rear-view mirror you can see the unit that receives the route information and also sends 'stopwatch' information derived from the vehicle's speedometer/odometer back via the roadside beacon to the control computer.

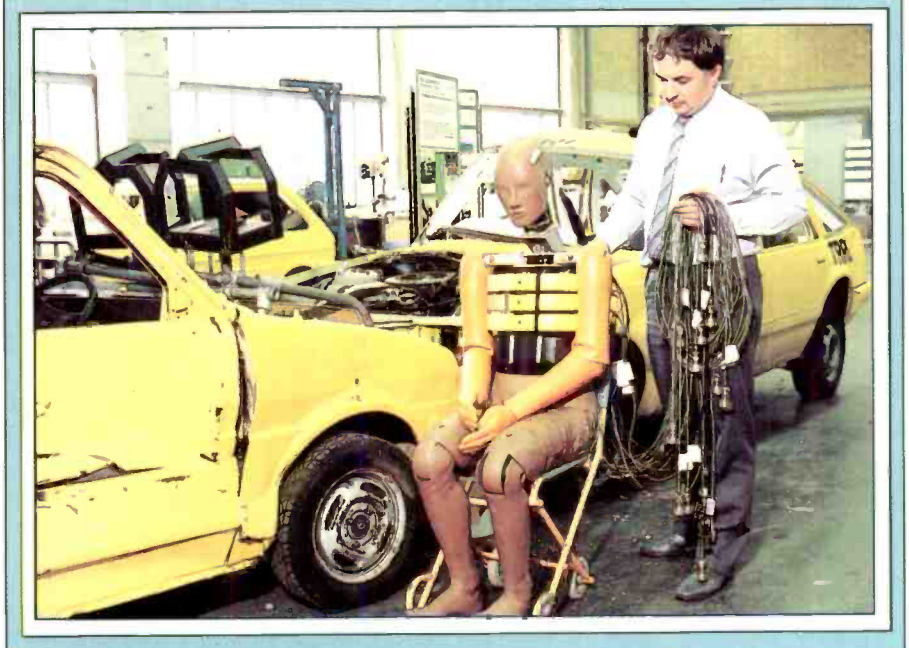
You can also see the remote-control unit used to enter destination data and the display unit in this picture. In the interests of safety, the remote-control unit only functions while the vehicle is standing still. How data is entered on the control unit will depend on the amount of software within the vehicle. In a basic system, grid references would be required but more sophisticated systems could easily accept street names.

Stopwatch information derived from the speedometer/odometer tells the control centre whether or not you have encountered delays on your route. If many drivers encounter the same delays to the extent that another route could result in a shorter travel time, subsequent drivers are sent along the alternative route.

Autoguide's in-vehicle control computer not only communicates between the roadside beacons and the driver but it also processes data from the speedometer/odometer and a magnetic heading sensor which is used to determine whether you have deviated from the prescribed route. This means that – in theory at least – you can never get lost.



UPDATE

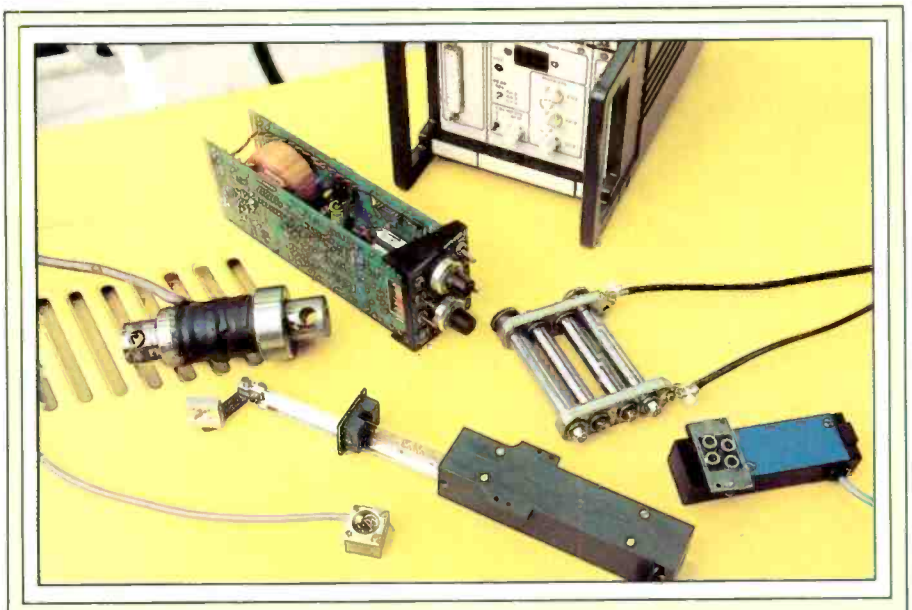


Individual cars are not tested at TRRL: the laboratory's job is to advise the Government on vehicle safety standards within the confines of manufacturing techniques of the day. Its job therefore is never ending.

Eurosid here is an impact-test dummy that could soon be standardized throughout Europe. You cannot see his electronic transducers but the umbilical that researcher Adrian Roberts is holding is evidence that they are abundant.

Vehicle sensors have been used with traffic lights now since lights were first introduced some 50 years ago. Early traffic lights had relatively simple control systems but in the 1970s, when electronic switching became more readily available, traffic light efficiency advanced gradually with the technology.

The computer board shown here is the heart of a new generation of traffic-light controllers called Mova. Most of the experimental work for Mova – modernized optimized vehicle actuation – was done on a PDP11/23A running Fortran 66, but traffic lights controlled by a PDP11 are not very practical. A significant part of the project involved transferring the essential functions of Mova onto the 68008-based board shown here.



Some of the transducers used inside the Eurosid crash-test dummy are shown here together with two signal-processing modules. On the left is a standard strain-gauge load cell for measuring axial compressive force on the femur and to the right of it is a load cell used to measure seat-belt tension.

Measuring impact displacement is particularly problematical. It is quite easy to measure slow-moving displacements but for impacts occurring within a few hundred of milliseconds, the task is not so simple. A number of options have been tried, including LVDTs (linear variable differential transformers) and high-quality linear potentiometers, but optical solutions have been found to be most practicable. The four-eyed device on the right measures displacement by reading reflections on a bar code. It works, but it is sensitive to rotation and changes in its position relative to the bar code.

A more fault-tolerant approach is the transmissive optical displacement transducer in the middle of the photograph, which has a linear Gray-code strip and light emitter/detecors.

The device in the left foreground is a single-axis accelerometer for measuring up to 750g. Child dummies often require three-axis devices costing £1000 but three single-axis accelerometers are generally preferred since they can be positioned more flexibly.

This junction on the infamous Hanger Lane gyratory system in west London is controlled by a Mova unit that can be monitored at TRRL via a modem link. Blue squares filled with white indicate a vehicle passing over a sensor.

Existing traffic light systems have three vehicle sensors at 40, 25 and 15m before the lights. These sensors serve to extend the 'green' signal or to recall the green signal if the lights are currently red.

Basically, an existing traffic light system knows that when a vehicle crosses a sensor, a green signal is required. When it gives that green signal depends on time limits that can be set for a given junction. This works well for quiet periods, but the system cannot evaluate traffic density during busy periods.

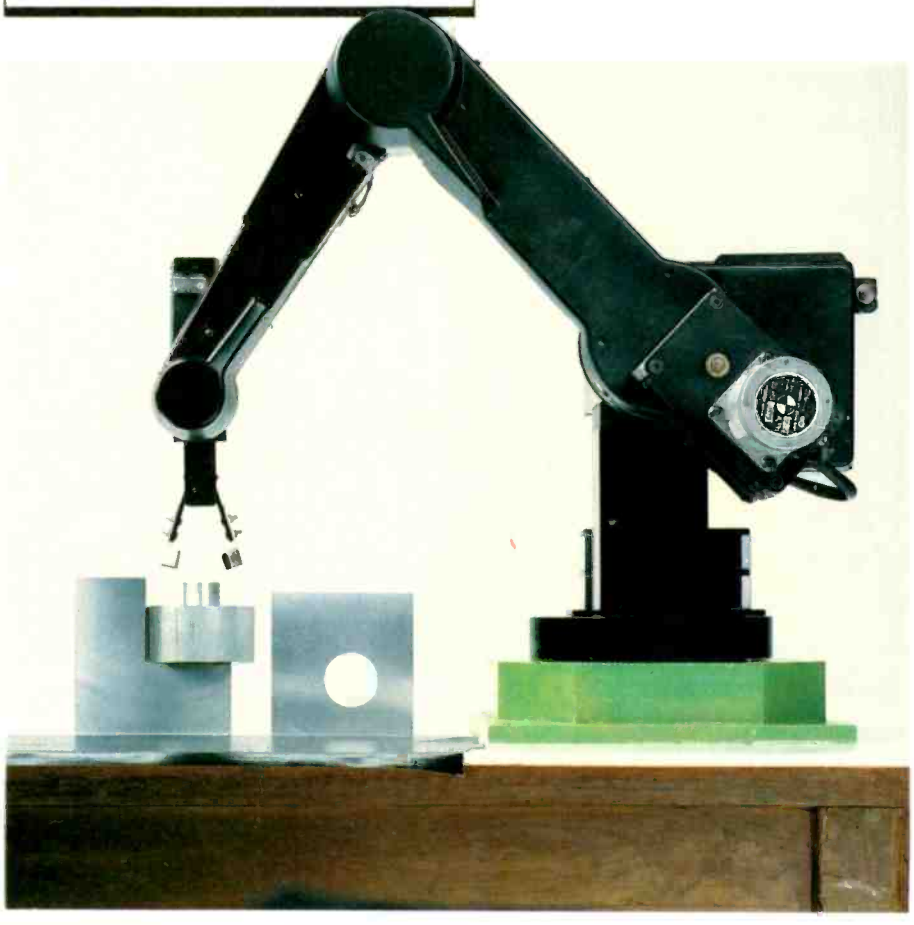
Mova has only two vehicle sensors at each junction approach but it is far more intelligent. For example, Mova has special features to cater for situations where a traffic-light approach is left with a significant queue at the end of a green signal. Under these conditions, the system judges the approach to be oversaturated and switches to a capacity-maximizing routine to clear the congestion. This and other such features of Mova could reduce average vehicle delay by about 13%.

UPDATE

British automatic arms firm establishes Russian base

One of the first British companies to embark on a joint venture with a Russian firm in the post-*glasnost* era is the Cambridge robot manufacturer Sands Technology. Sands has agreed to form a new Soviet-British company which will supervise robot production in Sverdlovsk's Scientific and Engineering Centre. The centre is backed by United Turbo Works and closely allied to the Urals Polytechnic.

For Sands Technology, the agreement involves supervision of SEC's robot production and advice on production and management techniques. Sands robots will be produced under licence in the USSR and marketed in the Comecon and Soviet sphere countries. David Sands, director of Sands technology, says, "There are many opportunities for British technology in the USSR and the Soviets urgently need Western technology".



As a result of one of the first joint ventures between a Russian and British company, robot arms like this one are to be produced under licence in the USSR. The agreement involves advice to Russia on both production and management.

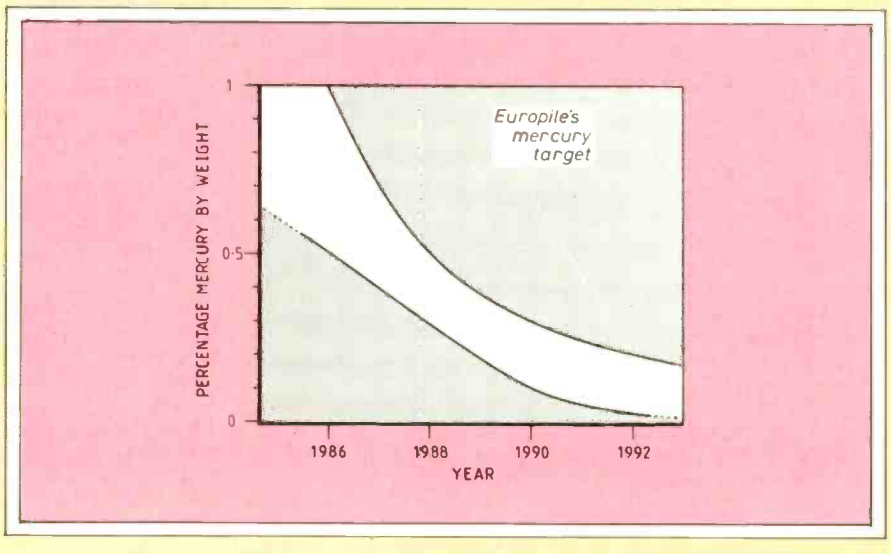
Green cells – battery makers clean up their act

These zinc chloride cells are described by their manufacturer, Panasonic, as "environment-friendly". Unlike conventional dry batteries they contain no mercury, and so there is no risk of the highly poisonous metal leaking into the soil when the cells are thrown away.

Other battery manufacturers which have announced "green" zinc chloride cells are Varta, Philips and Ever Ready. But removing mercury from the popular long-life alkaline cells is proving harder and progress has been slower. But Europile, the joyously-named consortium of European battery manufacturers, has agreed a programme for mercury reduction and most manufacturers – including Duracell in Britain – claim to be ahead of the targets.

By 1992, European battery makers hope to reduce the mercury content of their alkaline cells to well below one part in 1000 by weight.

Eliminating mercury altogether from alkaline cells entails quite a challenge for the battery chemist: without mercury, corrosion occurs inside the cell, gassing takes place and pressure builds up. Safety rather than performance is the reason given for retaining it.



Update continues on page 410

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Designer's guide to RS-232

GRAHAM STEPHENS

The communications boom has led to many products which make interface conformity claims by quoting 'RS232'. Subsequent purchasers are often disappointed and confused when this interface does not appear to be compatible with other 'RS232' implementations, or, even worse, when other standards such as 'RS423' are introduced as being virtually the same thing. However, some users are beginning to fight back by taking action against suppliers whose claims, a condition of purchase, are invalid. Other users regard interface conformity as indicative of product quality, and test it early on in their evaluation. Those who merely assume that all is well are taking significant short and long-term risks.

For better or worse, the RS-232 data communications interface standard based upon the 25 way 'D' connector has been with us for many years, and will no doubt continue to dominate the field. It is simple to implement, versatile, international, extremely well documented and excellently supported throughout the industry.

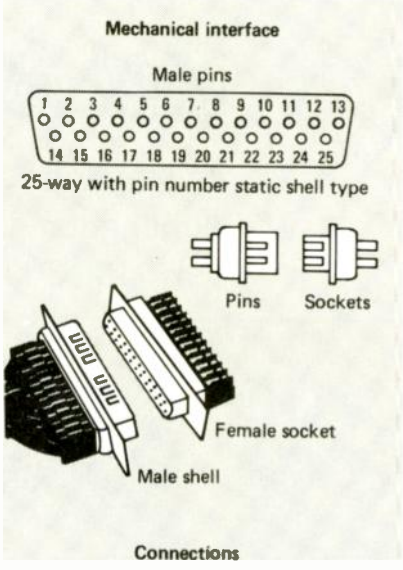
To function correctly, there must be agreement on the mechanical, electrical and functional characteristics. International agreement is contained within various specifications from the International Organization for Standardization (ISO) and the International Telecommunications Union (via its CCITT arm's 'V' recommendations). These bodies have worldwide authority, unlike the Electronic Industries Association (EIA) which is a trade association of equipment manufacturers in the USA under ANSI.

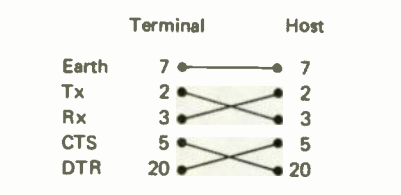
While all this may seem unimportant, it is necessary to maintain a realistic perspective on the position and status of EIA recommendations within world standards (although this in no way denigrates the major and pioneering contributions made by EIA to world standards). However, some people insist on quoting just EIA standards as though there is some kudos in doing so. Users are therefore confused and may consider 'RS232' to be superior in some way to international standards, without knowing if this is being used in a valid shorthand, legally evasive or 'semi-professional' manner. Whatever its mode of use, conformity claims which prove false arouse great interest among those well versed in trading legislation.

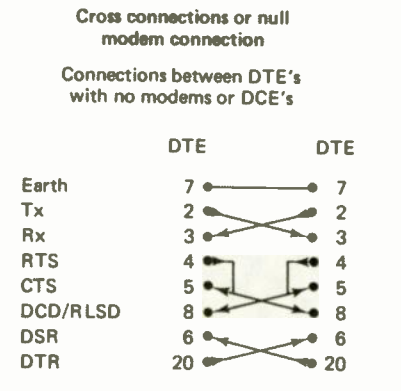
Another area where RS-232 is often quoted is modems. Regardless of manufacturer or supplier, a claim to conform to a CCITT 'V' modem recommendation also implicitly entails conformity to ISO 2110, V.24 and V.28. Nowhere is there any mention of RS-232. A 'V' modem interface has a 25-way 'D' socket (female contacts) with V.28 electrical characteristics and with pin allocation according to ISO 2110 functioning to V.24.

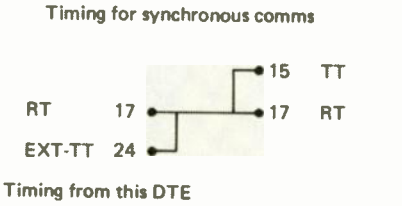
The most recent EIA '232' standard is "EIA-232-D" published in January 1987, which, to quote its foreword, is "a revision to RS-232-C, which brings it in-line with international standards CCITT V.24, V.28 and ISO IS 2110." (V.24, V.28 and IS 2110 refer to the functional, electrical and physical characteristics respectively: 232-D covers all three in broadly equivalent terms.) Presumably references to 'RS-232' must mean these latest standards, and 'RS-232-C' is not in-line with these international standards and may therefore need further clarification.

The remainder of this article is concerned with the electrical characteristics of the interface which are defined in CCITT V.28 and also within 232-D. The differences between them are of no practical significance.


Mechanical interface
Male pins
1 2 3 4 5 6 7 8 9 10 11 12 13
14 15 16 17 18 19 20 21 22 23 24 25
25-way with pin number static shell type
Pins
Sockets
Female socket
Male shell







ELECTRICAL CHARACTERISTICS

Measurements are made with respect to signal ground (or common return) which is the zero volt reference point. This appears on pin 7 only on the 25 way 'D' connector, and is the middle pin for both plug and socket so there should be no confusion. The actual point of measurement must also be determined. A terminal (DTE) and modem (DCE) connect together via an interface cable which may be sufficiently long to affect some of the characteristics. (Earlier recommendations – both EIA and CCITT – limited cable length to 15 metres or 50 feet. The only time that a 'scope was used was to wind a cable around it to measure its length!) This often brings a third supplier into the fray. Although 232-D is not helpful on this point, V.28 states that it is commonly accepted that the cabling is provided by the DTE, and that the interface point is at the junction of the DTE plus cable, and where this plugs into the DCE.

Generator (driver): space/zero/on/active/start, +5 to +15V; mark/one/off/idle/stop; −5 to −15V.

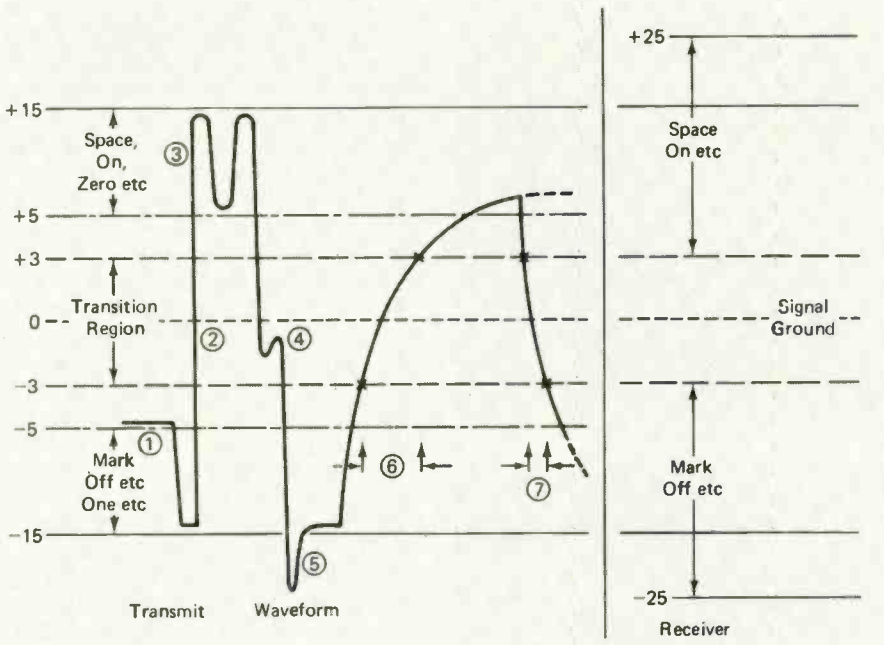
These voltages are measured with a load of 3k to 7k ohms (which is within ± 2V of signal ground) and a maximum capacitance of 2500pF.

The output resistance is not specified other than as not less than 300Ω in a power-off condition, and a maximum current of 500mA without driver damage when shorted to any other conductor within the cable.

These characteristics alone preclude the use of +5 or −5V power supplies to the driver device's output stage, and several claims have been seen where nominal TTL levels are said to be practically the same as 232. Not so much logic levels as bodge-it levels!

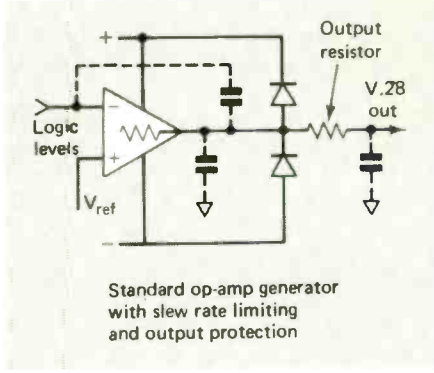
The maximum (instantaneous) slew rate is 30V/μs, and is often ignored by designers. The minimum slew rate is measured as the maximum time to cross the 6V transition region. For clock and data circuits this time is the lesser of 1ms or 3% of the nominal bit period, e.g. 1.5μs for the maximum allowed data rate of 20kbit per second (1ms is only significant for rates below 30 bit/s and may therefore be ignored). For control circuits, the maximum time is 1ms.

Remember that these signals may be measured before or after passage through a long interface cable, and data rate becomes very significant. This cable may also pick up interference from outside, or, if screened, quickly reach the 2500pF limit. If the screen is incorrectly terminated then even relatively short cables can cause major problems, and only circuits in use should be wired. 25-way ribbon cable may not be a good choice.

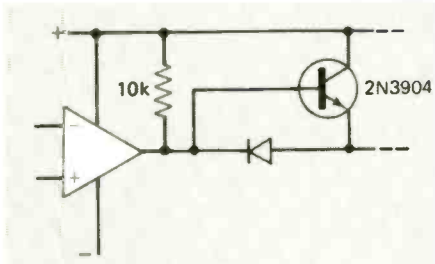


1. Fail – steady state not in range
2. Fail – slew rate greater than 30 volts per microsecond
3. Pass – lots of mains hum from psu, but steady state within range
4. Fail – change of direction within transition region
5. Fail – spike out of range (could be cable problem)
6. Fail – transition time too long (probably driving cable with too much capacitance)
7. Pass – smaller voltage excursion through same cable

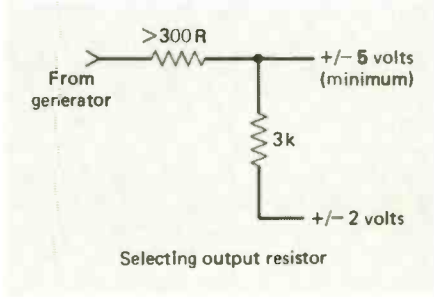
Electrical characteristics of an RS-232 link, showing good and bad signals.



Standard op-amp generator with slew rate limiting and output protection



339 with external active pull-up



Selecting output resistor

Receiver (load): greater than +3V is the equivalent of space/zero/on/active/start; less than −3V is the equivalent of mark/one/off/idle/stop.

The maximum test input voltage swing is ±25V.

The input resistance is 3k to 7k ohms to within ±2V of signal ground and over the range of ±3 to ±15V. The effective capacitance must not exceed 2500pF.

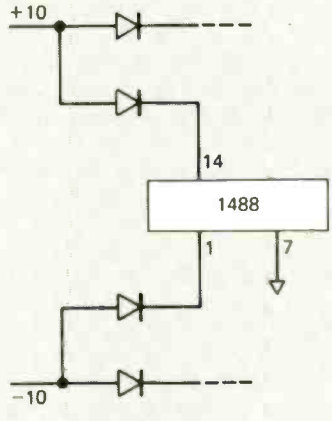
(It would appear that the resistance may be outside the 3k to 7k ohm range when within the transition region, and presumably allows for diode forward voltage drops).

The point of change (threshold) in the ±3V transition region is not defined. There may be two points to allow for hysteresis. These actual threshold voltage(s) may be varied according to application. Those close to zero may be too susceptible to interference. The most common threshold range is between +1 and +2V, and so a disconnected cable defaults to a detected '1'. However, it is sometimes useful to have a negative switching threshold so that a disconnection results in a detected '0' – to instigate a V.54 loop for example. Note that a power-off condition in the attached device may also appear as a disconnection.

GENERATOR IMPLEMENTATIONS

As has been mentioned earlier, driver output stages powered from five volt rails cannot conform even though they may work under favourable circumstances.

The simplest method of implementing a driver stage is to use a purpose-designed



Series protection diodes for each 1488 package

Protecting the 1488 RS-232 driver.

V.24/232-compliant integrated circuit, although a manufacturer's claim to conform to V.24 is meaningless. The most common device is the multi-sourced quad driver – the '1488'. Three of the drivers appear as a 2-input Nand, with the fourth as a simple inverter. The Nand function is rarely used as it gates the output ON rather than the more useful OFF. The inputs are TTL compatible, and should be tied high if unused. A pull-down resistor of 1kΩ may be necessary if driven by unbuffered 4000 cmos. As over 90% of data comms equipment failures are in the interface (usually the driver), this device should be socketed. This does not mean that the device itself is unreliable, merely that it is exposed to the unsuitable by the uneducated!

Power supplies are uncritical and do not require close regulation or matching. However it is advisable to insert series diodes (1N4001) in the supply leads to guard against hostile interface conditions, especially during power-up or while in power off. (This applies to all drivers, not just the 1488.) Power consumption tends to be proportional to the supply voltages but these should not be less than ±9V to ensure a safe margin on the output swing and correct short-circuit operation. Note also that a lower voltage swing usually permits the use of longer interface cables. Slew rate limiting is usually needed, and 330pF from output to signal ground is normally sufficient. In some instances, this value should be increased to prevent local interference, especially in rack-mounted applications. There is no consistent failure mode, although a fairly common one is where the output swings from near the positive supply to just above ground, rather than negative. This may look valid on some of the elementary interface monitors and cause an incorrect diagnosis.

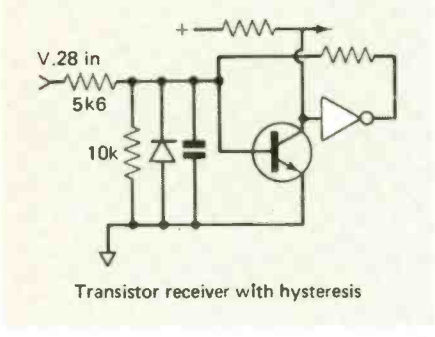
Other specialist devices are available. These include cmos versions of the 1488, mixed drivers and receivers, and those that generate the necessary power supply voltages internally. Should PTT approval be necessary, it has proved worthwhile to use

industry-standard devices as they tend to be well-known, and therefore exhaustive testing may not be thought necessary as long as their application is correct.

Non-specialist devices include op-amps, comparators, cmos buffers and, of course, resistors for permanent states. Quad op-amps with good slew rate and output swing are satisfactory for control signals and for lower data rates. The ubiquitous 339-type quad comparator may also be used for clocks and data with the addition of an active pull-up stage, and '4000' cmos buffers may be pressed into service. Each output should be protected by diodes to the power rails and a limiting resistor calculated to give the correct voltages into the worst-case load of 3kΩ with a 2V offset in the opposite direction.

RECEIVER IMPLEMENTATIONS

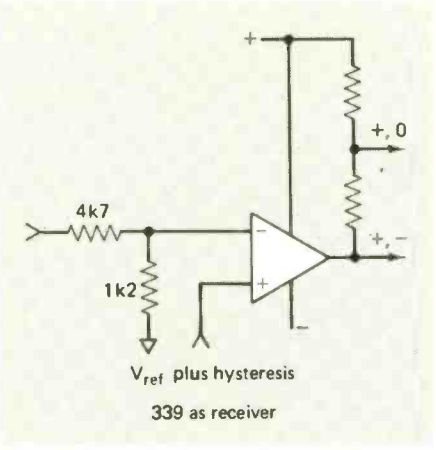
The receiver part of the interface generally consists of a resistance-matching load and a level-detecting switch. Inputs of greater than +3V are converted into the system's zero, and less than −3V into the system's one. Once again there are readily available standard devices, the most common being the quad '1489' type. The power requirements are +5V at about 20mA, and outputs are TTL compatible. Each receiver's input presents a resistive load of about 4k ohms to signal ground. Paralleling inputs (standby systems or patching) should do so through resistors to maintain the minimum 3k ohm load to the driver. (It is always disturbing to watch people with interface patching devices merely connecting several receivers to one driver on a trial-and-error basis to make something work. On the other hand, they keep service engineers in employment.)

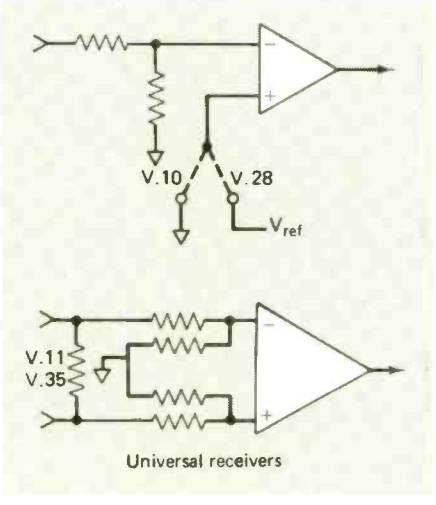


Transistor receiver with hysteresis

Each receiver has a 'response control'. This access point may be used to shift the input threshold voltages, as a decoupling point for noise spikes attenuation and as a normal input via an external resistor where the exact input resistance must be known. There are two varieties of 1489 IC – the 89 and 89A. With the response control open, the 89's positive-going threshold is about 1.2 volts and the negative going threshold is about +1 volt. The equivalents for the 89A are at +2 and +0.8 volts respectively, and this device is generally to be preferred.

The majority of applications seem to leave this control unused. Care should be taken to ensure that the open circuit input voltage does not go outside the ±2V specification. In most applications, it is much more useful to decouple the response control to ground to improve high frequency and impulse noise





rejection. It is very important to decouple as close to the pin as possible with a short ground track, otherwise a single input transition can result in a momentary spike on the output which is readily acted upon by edge-triggered logic.

Non-specialist receivers are generally designed to operate by a matching and attenuating resistive load feeding a level detector. Remember that this load must be between 3k and 7k ohms for both positive (+3 to +25) *and* negative (−3 to −25) input voltages. The simple transistor circuit needs a diode for the correct negative loading, and should include some hysteresis. Again, the 339 is useful for 4000 cmos interfacing, although there comes a time when the additional components begin to occupy significant areas of board. The differential inputs of comparators, however, simplify compatibility with other interface standards – notably V11 (almost 'RS-422') and V.35. Even the unbalanced V.10 ('423') can be accommodated easily. Probably the simplest 'universal' receiver is based upon the 26LS32.

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ANSI/EIA-232-D-1986 (Electronics Industries Association, Washington)

CCITT Fascicle VIII.1 of the Red Book (1984) Recommendation V.28 (I.T.U., Geneva 1985)

1488, 75188 and 1489(A), 75189(A) etc., (various manufacturers' data sheets) 26LS32, AMD data sheet

Graham Stephens works for Datex Ltd.

BOOKS

Smart Cards, principles, practice and applications, by Roy Bright. (SmartCard International Inc.). Review of the technical and commercial aspects of smart cards (cards containing memory plus a microprocessor for data management and security) and related technologies. Applications for these now extend far beyond the credit cards and electronic money of the financial sector, into the storage of medical and other personal data, control of access to services and to physical locations, telecommunications, and government uses. Included in the book is detailed information on trials and commercial applications of smart cards around the world, and some interesting material on identification and validation techniques, including emerging biometric methods such as vein-checking and electronic signature verification. The author's figures predict a global smart card population of 450-500 million by 1995, so we had better pay attention. Ellis Horwood, 173 pages, hard covers, £24.95.

SmartCard International's "Ulticard" includes a two-line LCD and a 64K reprogrammable memory. The travel company Thomas Cook, which is issuing it to business travellers, believes it could replace travellers' cheques. Holders can also use it to record and monitor business expenses.

World Radio TV Handbook, 1989 edition, edited by Andrew Sennitt. International directory of broadcasting stations, both radio and television, including the standard time and frequency service. Country-by-country entries list all transmitters of greater than flea-power, together with such details as station addresses, names of managers, local time, mains frequency and so on. HF, LF and MF stations are also listed by frequency. Feature section at the back includes articles on satellite television (transmission details are now included in the main directory), international radio relay agreements, and radio-related computer software; and there is a useful receiver buyer's guide. Billboard Ltd, 576 pages, soft covers. Available in the UK through Pitman Publishing at £17.95 from bookshops or by post for an extra £1.15 (Pitman are at 128 Long Acre, London WC2E 9AN). An update entitled Downlink is issued four times a year for a subscription in Europe of £9.

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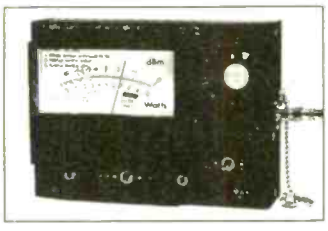

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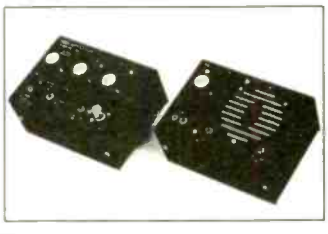

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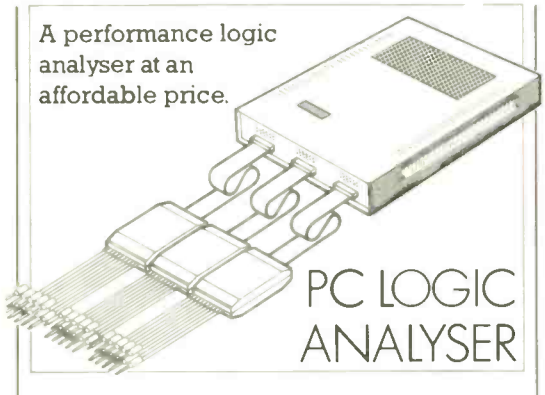

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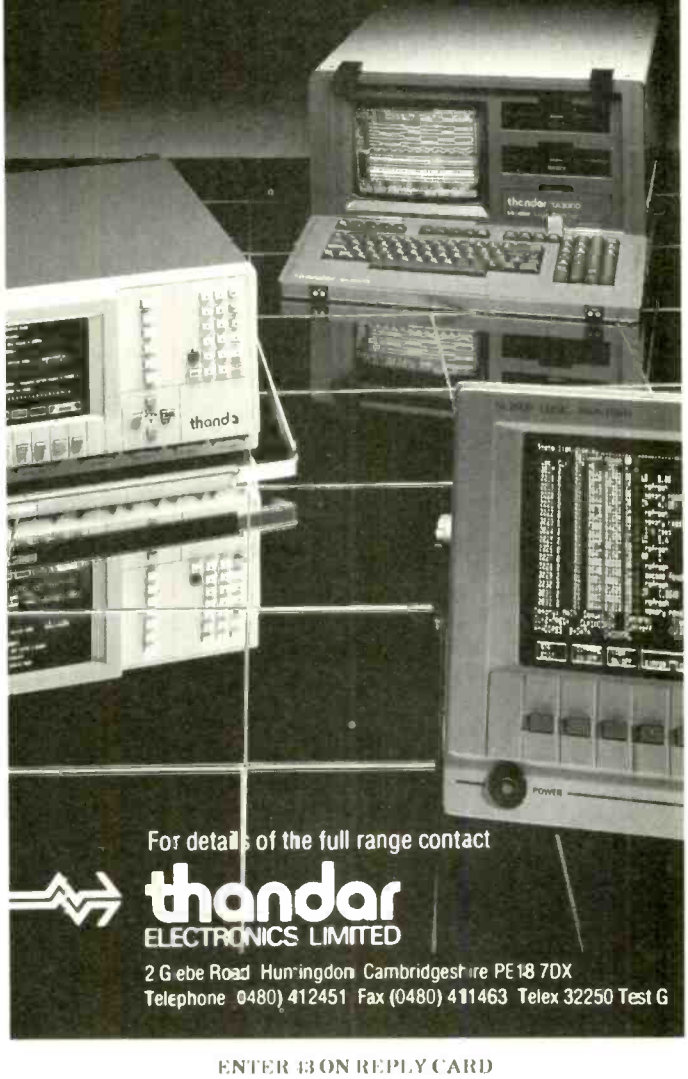

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High CMRR—no matching

An advance on the conventional three-op-amp instrumentation amplifier which needs no component matching for a high common-mode rejection ratio.

JOHN LIDGEY, CHRIS TOUMAZOU and COSTAS MAKRIS

Analogue differential (difference) amplifiers are generally based on a structure of resistive feedback around one or more op-amps and the ability of the circuit to reject common-mode signals relies on resistor ratios being precisely matched.

Figure 1 shows the conventional three-op-amp instrumentation amplifier which is widely used in applications requiring high differential gain, wide bandwidth and good common-mode rejection properties. The part of the circuit to the right of the broken line AA is a simple, single-op-amp, differential amplifier that will reject common-mode signals well if the resistance ratios $R_2/R_1 = R_4/R_3$.

The differential-mode gain of this stage is equal to R_2/R_1. The differential input/output pre-amplifier to the left of the line AA has unity common-mode gain and a differential-mode gain of $(1 + 2R_5/R_6)$. The complete circuit is effective in operation, but good CMRR performance means that R_1 to R_4 must be trimmed accurately to reduce the common-mode gain as much as possible. This trimming process adds considerable production costs in the manufacture of a practical amplifier.

To return to the input stage of the circuit of Fig 1, it is interesting to note that the current I in the R_5, R_6, R_7 network is directly proportional to the input voltage difference, that is

$$I = (V_2 - V_1)/R_6$$

and so this part of the circuit could be used to provide common-mode rejection if current I were made available as an output parameter rather than the output voltages of OA_2 and OA_1. The new instrumentation amplifier, based on this concept, is shown in **Fig.2.** Current-mirror symbols have been used to simplify the circuit diagram, the driven side of the mirrors (CM_1 and CM_2) being shown by the arrows, which also indicate the driving current directions. In practice, we have used high quality four-BJT current-mirrors, as we did previously when using the same supply-current sensing technique[1,2].

The operation is very straightforward and can best be understood by considering the node voltages and branch currents indicated on the diagram. Assuming that $V_2 > V_1$, then current flowing through R_1 is

$$I = (V_2 - V_1)/R_1$$

and, assuming that the current-mirrors operate with unity reflection, this same value of current is driven by CM_2 into resistor R_2, CM_1 merely cancelling the OA_2 bias current. Op-amp 3 is a voltage-follower used to provide a low-output-impedance drive. The role of CM_2 and CM_1 swap over when $V_2 - V_1$ changes polarity. The output voltage is given by $V_0 = IR_2 = (V_2\text{-}V_1)R_2/R_1$ or $A_{VD} = R_2/R_1$, this being the differential mode voltage gain.

In practice, the amplifier does not give zero common-mode output, this mainly being due to mismatches in the gain-bandwidth products of OA_1 and OA_1[3]. However, the CMRR performance is good and no resistor matching is needed. Slight departures from unity in the current-mirrors CM_1 and CM_2, together with relative

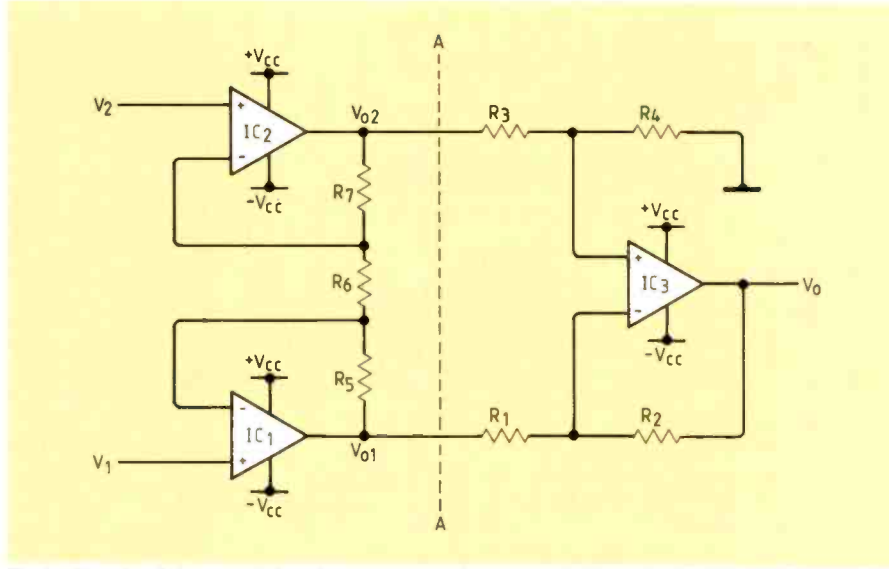

Fig.1. Standard form of the three-op-amp instrumentation amplifier, which requires attention to matching of resistors R_1 to R_4 to achieve good common-mode rejection.

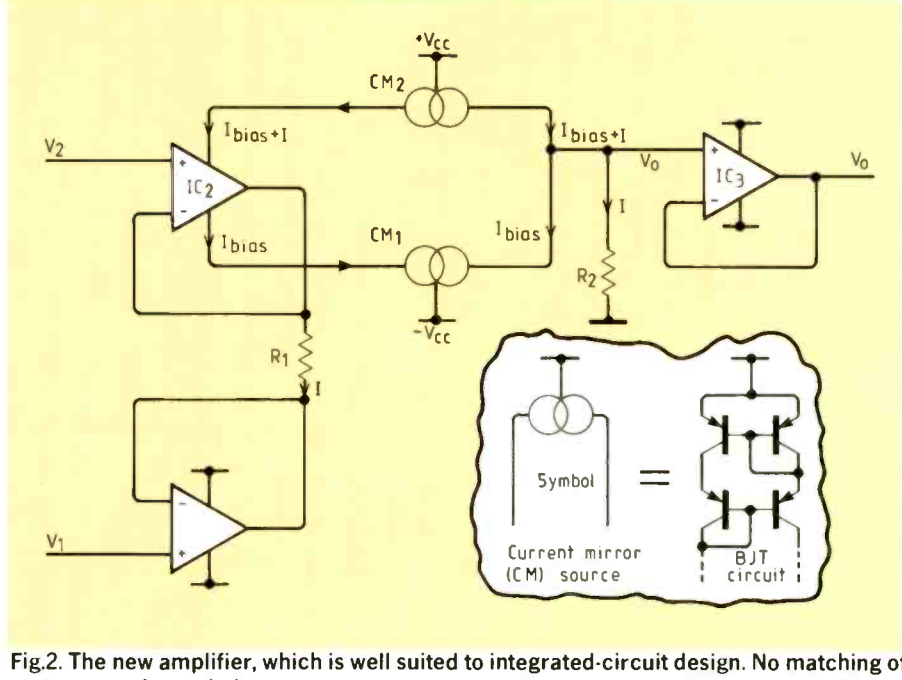

Fig.2. The new amplifier, which is well suited to integrated-circuit design. No matching of components is needed.

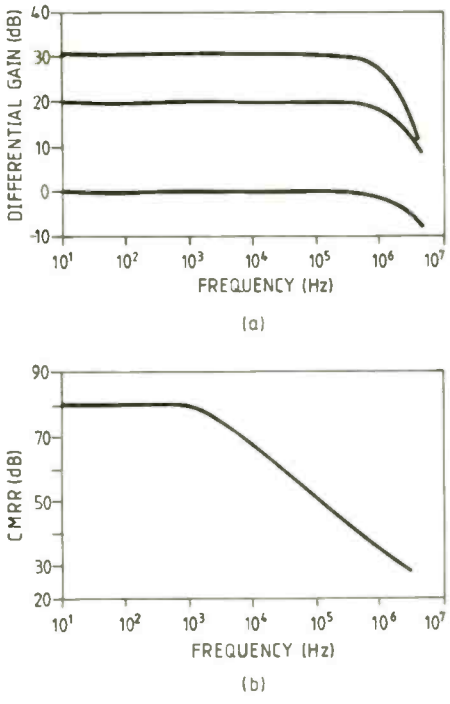

Fig.3. Differential gain of the new circuit, which offers constant gain/bandwidth at gains of 0dB, 20dB. Shown at (b) is the CMRR. An IC version of the design is being made, which will improve CMRR bandwidth.

imbalances between them, do contribute to some differential-mode distortion at the output, but these mirror imperfections do not degrade the CMRR figure at all.

We have built a test amplifier using a variety of single-chip op-amps with BJT current-mirrors. **Figure 3(a)** shows the differential-mode gain for R_2/R_1 set at 1000, 100 and 1. It is interesting to note that the gain bandwidth product is virtually constant[1]. **Figure 3(b)** shows the CMRR with unity differential-mode gain, which gives a respectable figure of 80dB up to about 1kHz. AD711 op-amps were used in the circuit for these measurements and the current-mirrors were constructed with CA3096 BJT arrays.

The amplifier is really no more complex than the standard three-op-amp instrumentation amplifier of Fig.1 and is ideally suited to integration. Recent developments have involved design and fabrication of an integrated-circuit version of the amplifier, which will improve both the CMRR low-frequency figure and the CMRR bandwidth, as OA_2 and OA_1 will be better matched than the two separate op-amps used in our tests.

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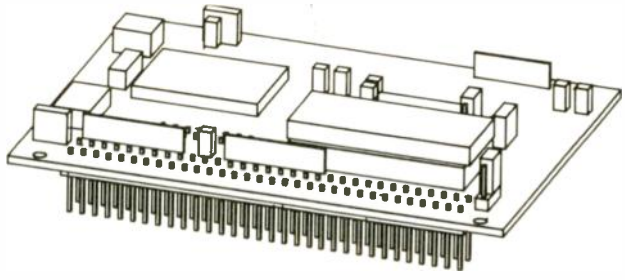

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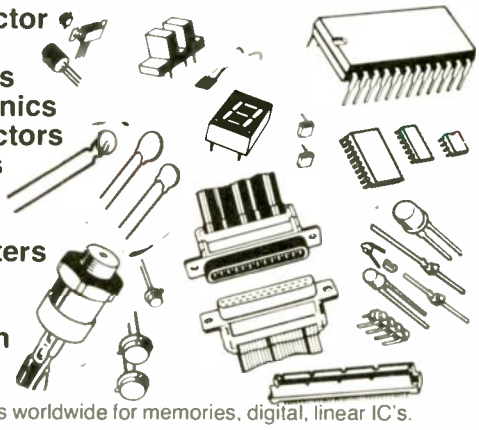

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A2900	12.75	EF85	0.90	PD500/510	4.30	1L4	0.65	6CX8	4.60	12AT6	1.95
AR8	1.15	EF86	1.45	PFL200	1.10	1R5	1.00	6CY5	1.15	12AT7	1.25
ARP3	1.15	EF89	1.60	PFL200*	2.80	1S4	1.00	6D6	2.50	12AU7	0.95
ARP35	1.15	EF91	1.60	PL36	1.60	1S5	0.75	6F6G	2.90	12AX7	1.10
ATP4	0.90	EF92	2.15	PL81	1.30	1T4	0.75	6F6GB	1.10	12BA6	1.80
B12H	6.90	EF95	1.90	PL82	0.70	1U4	0.80	6F7	2.80	12BE6	2.95
CY31	2.40	EF96	0.60	PL83	0.90	2X2A	3.80	6F8G	1.75	12BH7A	4.35
DAF70	1.75	EF183	0.75	PL84	0.90	3A4	1.30	6F12	1.60	12E1*	19.95
DAF96	1.35	EF184	0.75	PL504	1.25	3AT2	3.40	6F14	1.15	12J5GT	0.55
DET22	32.80	EF812	0.75	PL508	2.00	3B28	17.50	6F15	3.40	12K7GT	1.15
DF92	0.65	EFL200	1.85	PL509	5.65	3B28*	19.50	6F17	3.10	12K8GT	1.25
DF96	1.15	EH90	0.85	PL519	5.85	3D6	0.60	6F23	0.75	12Q7GT	1.15
DH76	1.15	EL32	0.85	PL802SE	3.45	3E29	21.85	6F24	1.15	12SC7	0.80
DL92	1.70	EL34	3.25	PY80	0.70	3S4	1.70	6F33	10.50	12SH7	1.25
DY86/87	0.65	EL34*	5.95	PY81/800	0.85	4B32	40.25	6FH8	18.80	12SJ7	1.40
DY802	0.70	EL82	0.70	PY82	0.75	5H4GY	4.85	6GA8	0.65	12SK7	1.45
E92CC	2.80	EL84	1.35	PY88	0.60	5U4G	1.85	6GH8A	0.90	12SQ7GT	2.20
E180CC	11.50	EL86	1.45	PY500A	2.75	5V4G	1.90	6H6	1.60	12Y4	0.70
E1148	0.75	EL90	1.75	QQV03/10*	5.95	5Y3GT	2.20	6J4	1.95	13D3	2.80
EA76	1.60	EL91	6.50	QQV03-20A	7.50	5Z3	4.85	6J4WA	3.10	13D6	0.90
EB34	1.15	EL95	1.80	QQV06-40A	27.50	5Z4G	1.25	6J5	2.30	19AQ5	1.85
EB91	0.60	EL519	7.70	QQV06-40A*	28.50	5Z4GT	2.20	6J5GT	1.50	19G3	11.50
EBC33	2.20	EL821	8.05	QV03/12	54.10	6/30L2	0.80	6J6	2.20	19G6	10.35
EBC90	0.90	EL822	9.95	SP61	5.75	6AB7	0.70	6J6W	2.80	19H5	38.00
EBC91	0.90	ELL80SE	4.50	TT21	2.50	6AC7	1.15	6JE6C	8.45	20D1	0.80
EBF80	0.95	EM80	1.35	TT22	45.00	6AG5	0.60	6JS6C	8.45	20E1	1.30
EBF89	0.80	EM87	3.00	UABC80	45.00	6AK5	1.90	6JU6	5.35	20P1	0.60
EC52	0.65	EY51	0.90	UBF80	0.75	6AK6	2.85	6K7	1.45	25L6GT	1.60
EC91	4.80	EY81	1.10	UBF89	0.60	6AL5	0.60	6KD6	12.90	25Z4G	0.75
EC92	1.85	EY86/87	0.75	UCC84	0.70	6AL5W	1.50	6L6	7.10	85A2	1.40
ECC81	1.25	EY88	0.65	UCC85	0.85	6AM5	6.50	6L6GC	9.60	85A2*	2.55
ECC82	0.95	EZ80	0.80	UCH42	0.70	6AM6	1.60	6L6GT/C	2.90	572B	61.90
ECC83	1.10	EZ81	0.80	UCH81	0.75	6AN8A	3.80	6L18	0.70	807	3.45
ECC84	0.60	GM4	8.90	UCL82	1.60	6AQ5	1.75	6LD20	0.70	807*	4.30
ECC85	0.75	GN4	6.30	UF41	1.85	6AQ5W	2.90	6LQ6	8.45	811A	13.50
ECC88	1.10	GY501	1.50	UF80	1.60	6AS6	1.15	6Q7G	1.30	812A	32.00
ECC189	1.20	GZ32	1.90	UF85	1.45	6AS7G	4.95	6SA7*	1.80	813	28.50
ECC804	0.65	GZ33	4.20	UL84	1.50	6AL6	0.90	6SG7	1.80	813*	44.00
ECF80	1.25	GZ34	2.45	UM80	1.80	6AX4GT	1.30	6SJ7	2.75	829B	16.00
ECF82	1.15	GZ34*	4.40	UM80*	2.30	6AX5GT	1.30	6SK7	1.85	829B*	24.00
ECF802	1.80	GZ37	3.95	UM84	0.95	6BA6	1.40	6SL7GT	3.50	866E	14.95
ECH42	1.65	KT77**	14.00	UY82	0.70	6BA6*	2.20	6SN7GT	1.50	931A	13.95
ECH81	1.25	KT88**	25.00	UY85	0.85	6BE6	1.75	6SQ7	0.95	931A*	19.80
ECH84	0.90	ML4	3.20	VR105/30	2.45	6BE6*	2.20	6SR7	4.60	954	1.10
ECL80	0.65	ML6	3.20	VR150/30	2.45	6BG6G	1.60	6V6G	1.50	955	1.10
ECL82	0.75	MX120/01	29.50	X61M	1.70	6BJ6	1.75	6V6GT	1.40	956	1.20
ECL83	0.75	N78	9.90	X66	4.95	6BQ7A	0.85	6X4	1.50	5763	5.75
ECL86	1.10	OB2	1.80	Z749	0.75	6BR7	4.80	6X5GT	0.75	6060	1.95
EF8	3.50	PCL82	0.95	Z759	19.90	6BW6	5.10	6Y6G	2.80	6080	7.30
EF22	3.90	PCL84	0.85	Z800U	3.45	6BW7	1.50	6Z4	1.75	6136	2.80
EF37A	2.15			Z801U	3.75	6C4	1.20	7Z4	1.90	6146B	12.70
EF39	1.10			Z803U	21.15	6CH6	7.50	9D6	2.15	9001	1.40
								11E2	19.50	9002	6.50
										9003	8.50

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Single-chip digital panel meters

The profusion of instruments on the market can make decision difficult. Mr Wyre of Lascar Electronics discusses the differences.

SIMON WYRE

More and more original-equipment manufacturers are fitting digital panel meters (DPMs) to their products in preference to the older moving-needle, or analogue, instruments. The reasons are many and are concerned with accuracy, freedom from scale reading errors, ease of scaling, simple calibration, auto-zeroing and low cost.

In many DPM applications, little or no signal conditioning is needed, in contrast with those using analogue types, which often need amplifiers to match impedances. Any cost advantage in using analogue meters is quickly eroded in these circumstances.

There are other, less technical reasons for their adoption. The design of test equipment does not stop with the circuit diagram: ergonomics, physical appearance and the overall product "image" must also be considered by the designer and by those who market the equipment.

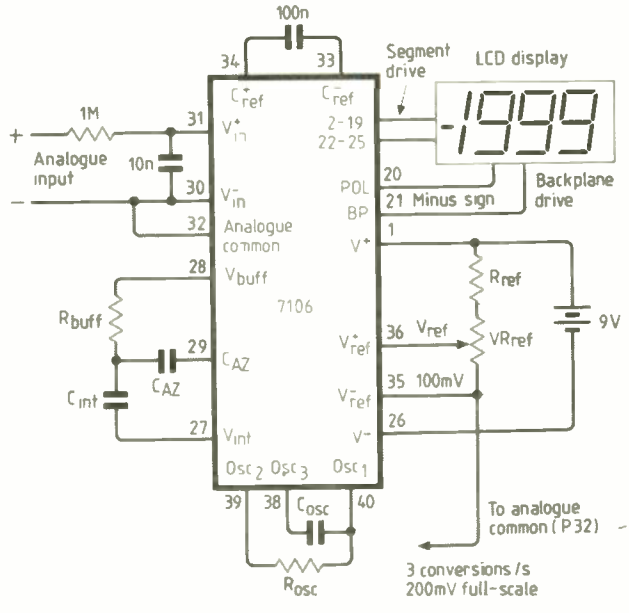
The techniques of A-to-D conversion and digital frequency conversion have been well known for many years, but the construction of digital meters using discrete components and small-scale ICs was not financially feasible. The appearance of large-scale ICs changed the picture.

In the ten years since the first single-chip meter/display drives emerged, they have revolutionized the design of panel instruments and made possible new designs that were not possible with earlier components. Most of them need only a few passive components and a display to provide an accurate, reliable and low-cost instrument.

By the term "single-chip", I mean an integrated circuit which can accept an analogue or frequency input and convert it to drive a digital display directly. I have excluded microcontrollers with A-to-D inputs and LCD drive, since they need to be programmed and I do not regard them as "off-the-shelf" components.

Panel meter ICs can be categorized by their type of display and by the number of digits in the display. The somewhat bizarre expression "4½ digit display" refers to the fact that it will read up to 19999, while 3½ types will read 3999. In the list of currently available equipment, I have not entered into details of specification, since makers' data sheets provide full information.

Fig.1. A basic ICL7106 meter application circuit.



A-to-D CONVERSION

Conversion in panel instruments is almost exclusively performed by means of the dual-slope technique, which possesses a number of advantages over other methods.

- it is accurate
- external passive devices are not critical
- most ICs have bipolar inputs, accepting negative or positive inputs
- resolution can be up to 15 bits plus sign (19999)
- measuring and reference inputs are differential
- noise immunity is high
- auto-zero operation
- rejection of supply-borne disturbances is good
- common-mode rejection is high

The most popular meter ICs were introduced by Intersil following a development for Fluke, who needed low-cost, reliable multimeters for which the best solution was a custom-designed chip for A-to-D conversion and display drive; a spin-off from this work was the 71XX series of DPM ICs. In its basic form, a 3½ digit chip, it is still the most popular; other makers have second-sourced many of the original Intersil chips and have gone on to make their own. The table lists the available DPM chips and their manufacturers.

One other method of A-to-D conversion is charge balancing, used in the Ferranti ZN451E. This device operates as low as 1.999mV full scale. In this design, the input is applied to a voltage-controlled oscillator whose output frequency is measured by a digital frequency meter.

The choice of devices is so extensive as to be bewildering and the small print in IC specifications will repay study. Figures quoted mostly relate to the analogue inputs and, since the inputs encounter linear (op-amp) circuitry, it is not surprising that they bear a close resemblance to op-amp specifications. The most important thing to remember is the limitation imposed on the common-mode range of the inputs: I have seen very embarrassing attempts to measure the output current of high-voltage supplies

by placing the shunt in the positive rail, when the meter is referred to 0V!

GLOSSARY

One or two of the terms used in manufacturers' data sheets might need explanation.

Auto zero. During the conversion cycle, the chip disconnects the inputs and applies a short circuit to the converter input. Any offset reading is stored in a capacitor or in the output counter and added or subtracted from the reading to give true zero. The ZN451 can drive external switches to include any conditioning circuit in the auto zero action.

Common-mode range. Most meter ICs must keep their analogue inputs between the supply rails to give stable and linear results. The CMR specifies how close the inputs may approach the rails.

Differential input. Measuring and reference inputs are normally taken to two pins, the difference between them being the voltage to be measured. The meter will operate correctly provided that the voltages on the inputs are within the common-mode range of the meter. This facility is particularly useful for measurements on bridge circuits.

Ratiometric operation. A typical application is the comparison of a voltage against a known reference, which may itself be a variable. If the same current passes through known and unknown resistors, the meter will measure the voltage drop across each and give a direct reading of the ratio of their values.

Ratiometric operation. A typical application is the comparison of a voltage against a known reference, which may itself be a variable. If the same current passes through known and unknown resistors, the meter will measure the voltage drop across each and give a direct reading of the ratio of their values.

Single-ended operation. Most meters will only operate within their specified CMR, but for many applications the input must be referred to power supply ground. One method of overcoming the problem is to use ±5V supplies and another is to use a negative-rail generator such as in the ICL 7660. MAX138 and MAX139 devices have this facility built in.

A-TO-D CONVERTER TYPES

ICL7106. All types in this group are pin-compatible and need only slight changes in the values of passive components. The 7136 can be recommended for new designs; it uses less power, offers fast recovery from overrange and employs higher-impedance passive components, which are therefore smaller. **Figure 1** shows the core of a typical application.

The MAX 138 is almost pin-compatible with the 7106 but, with two extra capacitors, will operate from a single 5V supply with the instrument connected to 0V.

ICL7116. This is virtually pin-compatible with the 7106, but has a DISPLAY HOLD input to maintain the reading indefinitely

Table 1. A/D converter ICs

TYPE	VARIANT	MAKER	DISPL	RANGE	SUPPLY (Excluding LED drive current)	SPECIAL FEATURES
ICL7106	ICL7106	INTERSIL	LCD	3½	9V 1mA	The original LCD meter chip
	ICL7106	MAXIM				
	TSC7106	T'DYNE				
	TSC7106A	T'DYNE				ICL7106 with low drift internal reference. Tempco. 50ppm/degC max.
	MAX130	MAXIM			9V 250µA	As 7106 but with lower power and precision bandgap reference
	ICL7126	INTERSIL			9V 100µA	Low power version of ICL7106
	ICL7126	MAXIM				
	TSC7126	T'DYNE				
	TSC7126A	T'DYNE				ICL7126 with low drift internal reference. Tempco. 70ppm/degC max.
	ICL7136	INTERSIL			9V 100µA	As ICL7126 but with fast recovery from overrange inputs. Replaces the 7126
	ICL7136	MAXIM				
	TSC7136	T'DYNE				
	TSC7136A	T'DYNE				As 7136 but with low drift internal reference. Tempco. 75ppm/degC max.
	MAX131	MAXIM				As 7136 but with precison bandgap reference.
	MAX138	MAXIM			5V 200µA	Like ICL7136 but with on-board-ve rail generator for 'single ended' operation.
ICL7116	ICL7116	INTERSIL	LCD	3½	9V 1mA	ICL7106 but with digital hold in place of Ref LO input
	ICL7116	MAXIM				
	TSC7116	T'DYNE				
	TSC7116A	T'DYNE				ICL7116 with low drift internal reference. Tempco. 50ppm/degC max.
	MAX136	MAXIM			9V 100µA	ICL7136 but with digital hold in place of REF LO input
	TSC810	T'DYNE				Low drift reference 75ppm/degC max.
	TSC811	T'DYNE				Similar to TSC810 but with differential reference and digital hold.
ICL7107	ICL7107	INTERSIL	LED	3½		The original LED meter IC with 8mA direct segment drives
	ICL7107	MAXIM				
	TSC7107	T'DYNE				
	TSC7107A	T'DYNE				ICL7107 with low drift internal reference. Tempco. 50ppm/degC max.
	ICL7137	INTERSIL			+5V 100µA	Low power version of the 7107
	ICL7137	MAXIM			−5V 50µA	
	MAX139	MAXIM			5V 200µA	Like ICL7137 but with on-board-ve rail generator for 'single ended' operation
ICL7117	ICL7117	INTERSIL	LED	3½	+5V 1mA	ICL7107 but with digital hold in place of REF LO input
	ICL7117	MAXIM			−5V 1mA	
	TSC7117	T'DYNE				
	TSC7117A	T'DYNE				ICL7117 with low drift internal reference. Tempco 50ppm/degC max.
ZN450	ZN450	FERRANTI	LCD	3½	5V 4.5mA	Full scale 1.9mV. Display hold, offset null inputs.
ZN451E	ZN451E	FERRANTI		3½	5V 4.5mA	Full scale can be as low as 1.9mV. External auto zero loop, overrange/underrange outputs, digital auto zero.
ICL7129	ICL7129	INTERSIL	LCD	4½ (⅓ Triplex)	9V 1mA	4½ digit resolution, overrange and underrange o/ps, digital selection of 200mV or 2V full scale, digital hold, low bat indicator, continuity indicator 110dB CMRR, digital auto-zero operation needs no auto-zero capacitor.
	TSC7129	T'DYNE			9V 0.5mA	As ICL7129 but with lower power and no need for integrator snubber.
	ICL7129A	MAXIM			9V 1mA	Very low noise inputs (3µV typ.). No need for integrator snubber.
	MAX7129	MAXIM				Low noise (7µV typ.). Very low input leakage current (1·3pA typ.).
	TSC829	T'DYNE				Similar to TSC7129 but with each digital signal brought out separately. Also a continuity buzzer output and µP interface. Available only in a 60 pin flat pack.
AUTORANGERS						
TSC805	TSC805		LCD	3½ (⅓ Triplex)	9V 1mA	Autoranging with 22 operating ranges, continuity buzzer drive, low drift ref, range/function annunciators. Available in 60 pin surface-mount only.
	TSC815	T'DYNE				Very similar to TSC805 but with digital hold.
	TSC816	T'DYNE				Very similar to TSC805 but with digital hold and 24 operating ranges.
ICL7139	ICL7139	INTERSIL	LCD	3¾ (½ Duplex)	9V 1.5mA	Autoranging with 13 operating ranges, continuity buzzer drive, display annunciator, display hold. Available in 40 pin DIL.
	ICL7149	ICL7149				As ICL7139 but with 18 ranges.
BARGRAPH CHIPS						
TSC826	TSC826	T'DYNE	LCD	40 BAR	9V 125µA	Bar or dot display, overrange and polarity indication, hold input, precision reference, 20mV to 2V full scale. Available in flat pack only.
ICL7182	ICL7182	INTERSIL	LCD	101BAR (½ Duplex)	5V 350µA	Single ended operation, overrange and polarity indicators, precision reference, internal oscillator, user selectable annunciators. Available in 40 DIL or flat pack.
TSC827	TSC827	T'DYNE	LCD	101 BAR (⅓ Triplex)	9V 1.4mA	Two set points with annunciators and outputs, overrange and underrange annunciators and outputs, 1000 resolution serial data output. PLCC pack.

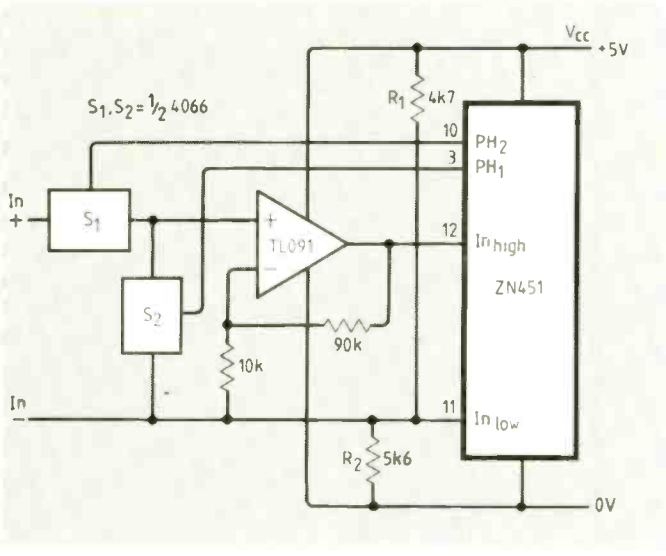


Fig.2. Auto zero in the ZN451, using series and shunt switches to disconnect the inputs and short circuit the device inputs.

Fig. 3. ICL7129 application circuit.

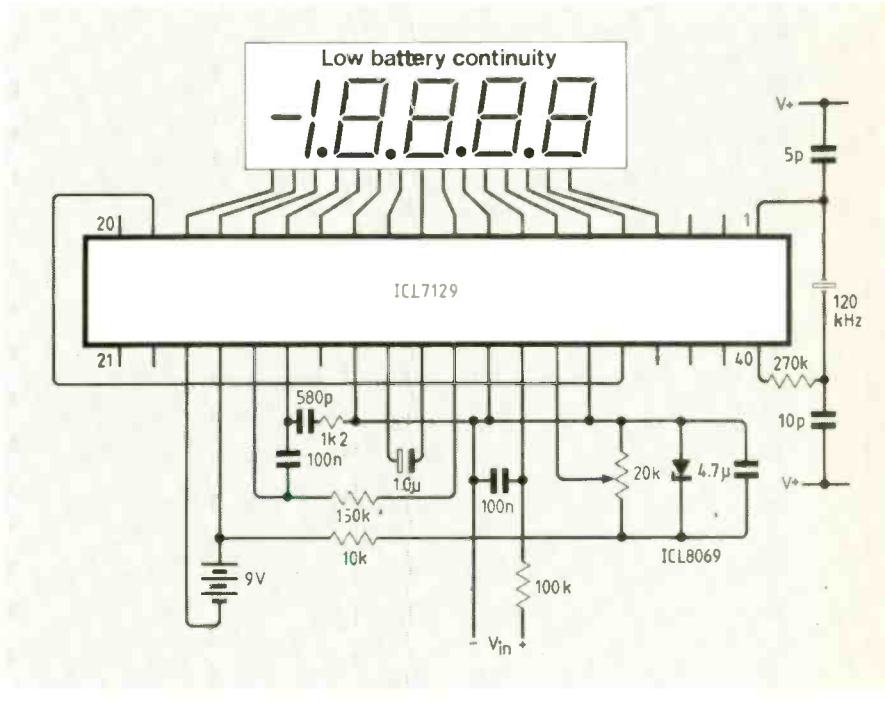
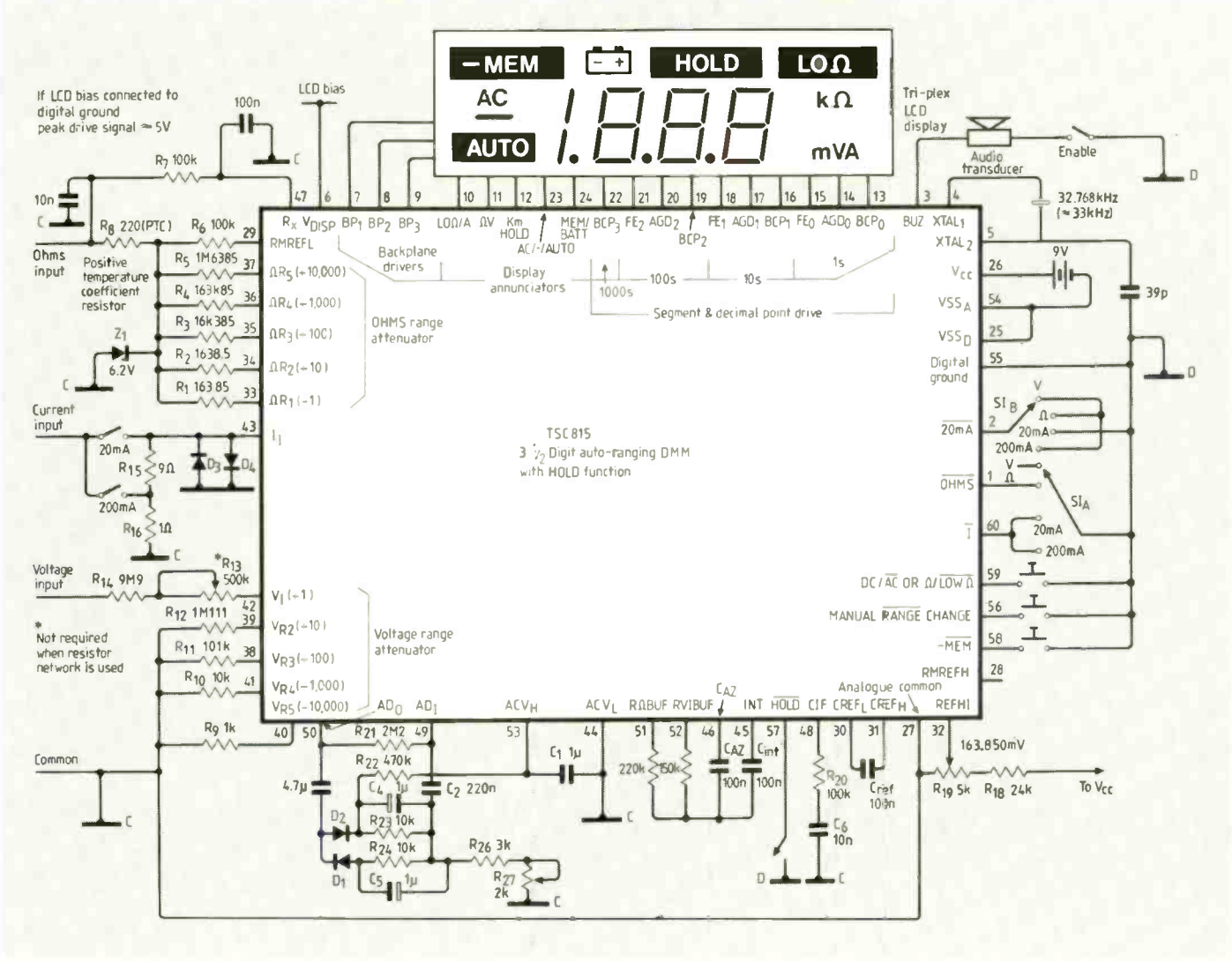


Fig.4. TSC815 autoranging IC with digital hold.



when connected to the positive line; the meter free-runs if this input is disconnected or taken to the TEST pin. The MAX136 does not have an internal pull-down to TEST (which doubles as digital ground in LCD meters) and needs an external resistor.

TSC811. Since only 40 pins are available, the 7166 type has REF LO connected to COM to free a pin for the HOLD input. The TSC811 keeps the differential reference but loses one of the oscillator pins: it therefore needs a crystal to set the clock timing.

ICL7107. This is nearly pin-compatible with the 7106, but has a digital ground instead of the LCD backplane signal. 7107s drive common-anode, seven-segment LEDs directly, each driver having a constant-current output of 8mA. Power dissipation is high and temperature has a tendency to increase, affecting the internal reference, so that it might be necessary to use an external reference. Types with low-drift internal references present less of a problem. The 7137 is only fortuitously a low-power version: the means whereby this is obtained also provides fast over-range recovery and low noise.

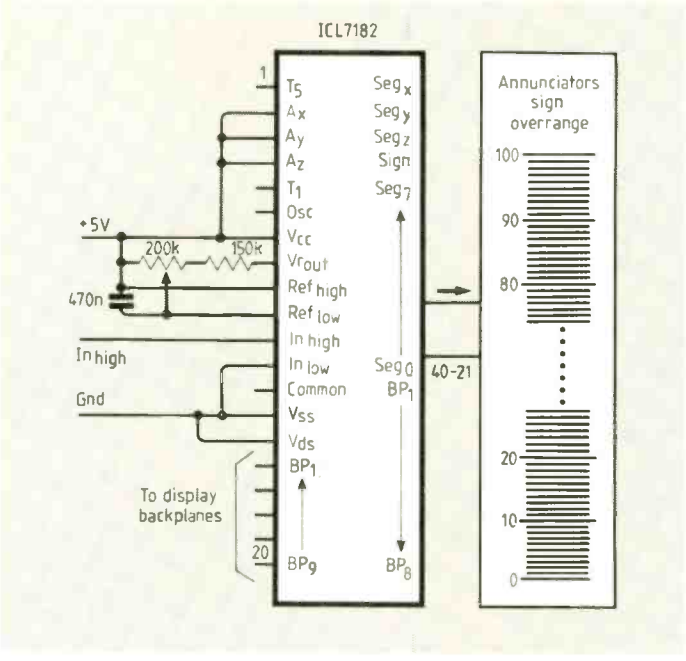


Fig.5. ICL 7182 with bargraph indicator.

MAX139 is intended for single 5V operation.

ICL7117. As 7107, but with the HOLD feature.

ZN450. This uses the charge-balancing method of conversion and operates down to less than 2mV full scale. Provision of an offset null allows tare removal in weighing equipment. Connection to the LCD is similar to that of the 71XX chips.

ZN451. Similar to the 450, but with the addition of outputs to include external circuitry in the auto-zero process. **Figure 2** shows the circuit.

ICL7129 (Fig.3). As a 4½ digit instrument, this uses two successive integrations to achieve a 5½ digit internal conversion, which is used to give the final result. The use of a triplex display frees many pins for hold, over-range and other uses. There are two logic-selected ranges.

TSC829. The pin saving referred to in the 7129 needs careful use, since some pins have a dual function. The TSC829 avoids the problem by means of a 60 pin package, which also provides outputs for a processor interface and a continuity buzzer.

AUTORANGING CIRCUITS

The principle of autoranging is to connect a series of mos switches to a set of precision external resistors, the set in use being selected by the function input. As an out-of-range condition occurs, the range is changed by the attenuator/shunt selected.

Fig.6. ICI7216 frequency meter.

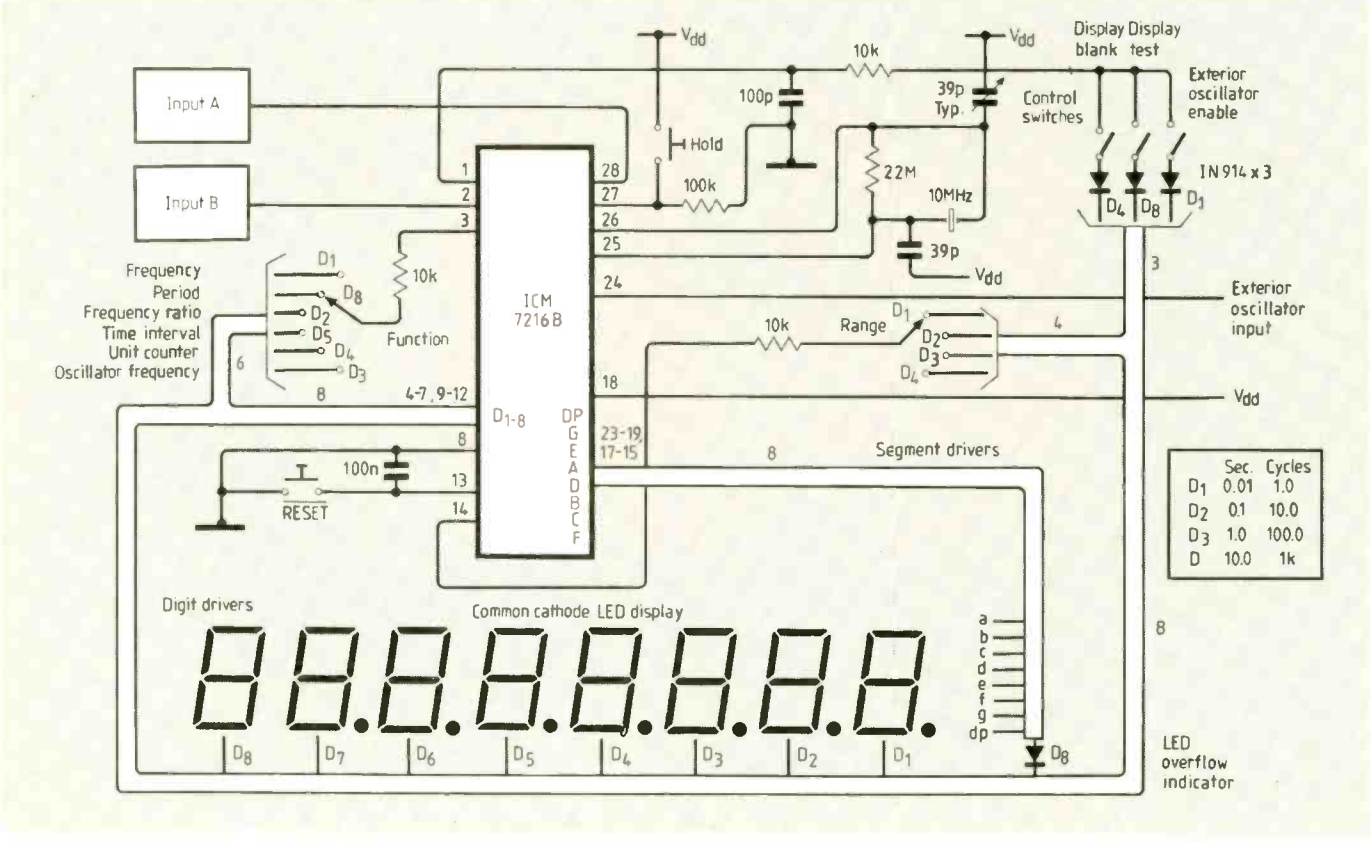


Table 2. Frequency meter ICs

FREQUENCY METER CHIPS			DISPL. SIZE		SUPPLY (Excluding LED drive current	
ICL7216	ICL7216A	INTERSIL	LED	8 Digit	5V 2mA	Common anode. Counts frequency, time, frequency ratio, unit and period.
	ICL7216B	INTERSIL				As 7216A but common cathode.
	ICL7216C	INTERSIL				Common anode. Frequency counter only.
	ICK7216D	INTERSIL				As 7216C but common cathode.
ICL7226	ICL7226A	INTERSIL	LED	8 Digit	5V 2mA	Common anode. Counts freq., time, freq. ratio, unit and period. BCD outputs.
	ICL7226B	INTERSIL				As ICL7226A but for common cathode.

The devices also need display outputs to drive decimal points and function indicators. This technique entails the use of very stable resistors in very odd values. **Figure 4** shows a typical application circuit.

BARGRAPH CIRCUITS

In most respects, these resemble ordinary 3½ or 4½ digit ICs with their outputs in the form of a bar or moving dot.

TSC826 will drive a 40 segment bar with polarity and over-range indication.

ICL7182. This uses a multiple backplane duplex drive to give 101 segments with polarity, over-range and three user-selectable segment inputs. **Figure 5** shows the arrangement.

TSC827. In a 60 pin flat pack, this has a triplexed 101 unipolar display but with two programmable set-points (with indicators) and a serial data output.

FREQUENCY METERS

There are fewer of these A-to-D types available, since not only is there less demand, but also most of the counter/driver ICs can be fitted with gating circuits to convert them to frequency meters.

ICL7216/7226 are similar in operation, both accepting two inputs for frequency, frequency ratio, period, elapsed time and count. The 7226 is in a larger package and has BCD outputs. The 7216 is shown in **Fig.6.**

Further information

The Intersil Component Data Catalog. GE/RCA Solid State International Ltd. Beech House. 373 London Road. Camberley. Surrey GU15 3HR. Telephone 0276 685911

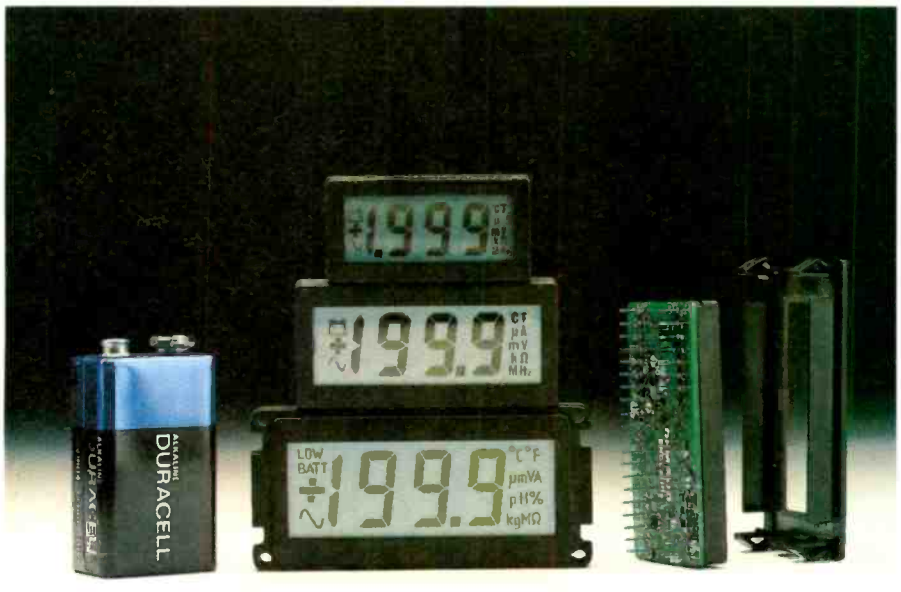
Ferranti Semiconductors ZN450/451 data sheets. Ferranti Electonics Ltd. Gem Mill. Fields New Road. Chadderton. Oldham. Manchester OL9 8NP. Telephone 061 624 0515

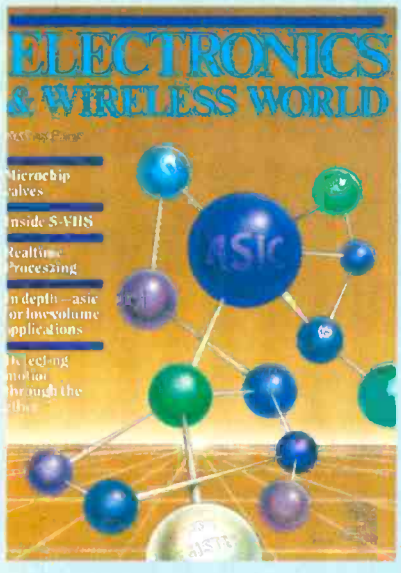
Maxim Data Converters and Voltage References. Maxim Integrated Products UK Ltd. 2 Whitchurch Road. Pangbourne. Reading. Berks RG8 7BP. Telephone 07357 5255

Teledyne Data Acquisition IC Handbook. Teledyne Semiconductor. The Harlequin Centre. Southall Lane. Southall. Middlesex. Telephone 01-571 9596

Digital Panel Meter Handbook. Lascar Electronics Ltd. Module House. Whiteparish. Salisbury. Wiltshire. Telephone 07948 567

DPMs from Lascar Electronics. Top to bottom: DPM 400; DPM 500; and DPM 2000. All use the ICL 7136 fast-recovery chip





NEXT MONTH

Getting into asic. Custom chips were once the preserve of Hewlett-Packard, IBM and other industry heavies. Designer chips can now find a place in your product – or your competitors' – for under £1000 with samples thrown in. These are true custom metallised gate array products, not just a programmable standard logic array. Our in-depth look at asic concentrates on custom chips for small companies. We consider both programmable logic and true gate array processes.

Inside S-VHS. Dr Johnson once said "A woman preaching is like a dog walking on its hind legs. It is not done well but you are surprised to find that it is done at all". The good doctor would surely have been equally damning in his praise of the old VHS standard. S-VHS represents a genuine improvement in the picture quality of domestic video, possibly the first in ten years.

Running realtime I/O with the Z80 and Z280 processors. Concurrent subroutines form the basis of a real improvement in the efficiency of realtime task execution. This article is a must for programmers with an intellectual investment in Z80 code.

Integrated high vacuum valve circuits. Valve technology has been brought up to date and seems set to make a comeback. You probably wouldn't recognise it: no glowing cathodes, glass envelopes or lethal voltages. Look for multiple cold cathode valves integrated onto a micro chip structure, CRTs without heaters and a new generation of flat panel display technology. The new valves also promise microchip performance in the most hostile environments.

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Philips PM8235 Multipoint recorder up to 12 channels (2)	£375
Rohde & Schwarz SMA1 UHF Signal gen 500-1800MHz (1)	£2,500
Rohde & Schwarz SMB1 SHF Signal gen 1.7-5.0GHz (1)	£2,000
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Tektronix 8002 development system inc: Z80, and 8085 IC emulators with 4024 video terminal, manuals, software and spare discs	£2,000
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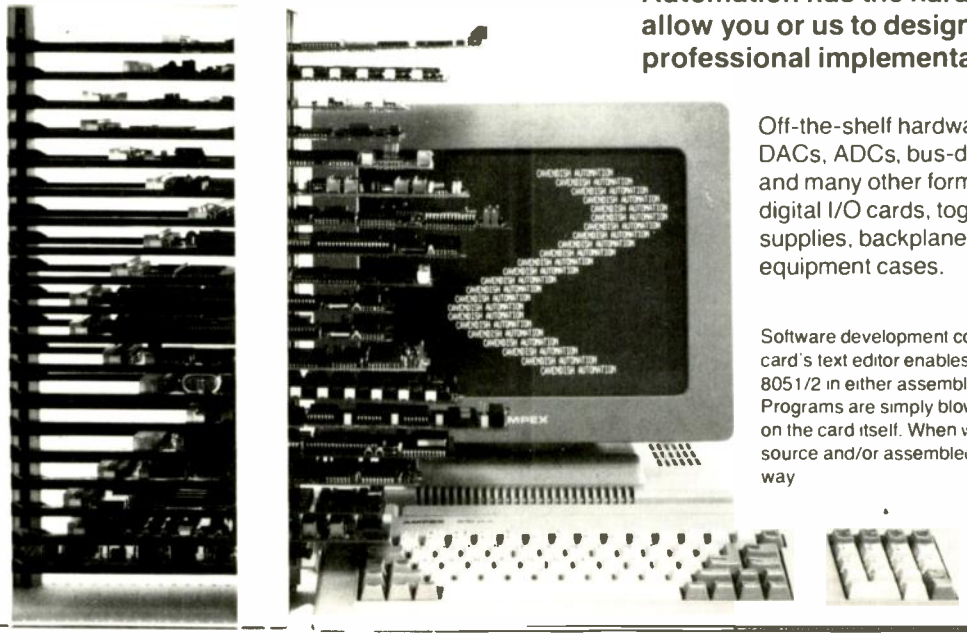

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Linear array. The flexible Linear Array (FLEXAR) from EXAR offers the fast turnround and flexibility of semicustom and the low unit cost of full custom. The series also includes thin-film resistors and Schottky diodes and operates at an f_t of 1GHz. Microlog Ltd 04862 29551

A-to-D and D-to-A converters

8-bit A-to-D converters. Monolithic c-mos A-to-D converters feature a 6 microsecond conversion rate – including sample-and-hold acquisition – to allow digitization of a 0V-5V sine wave at 40kHz with better than 45dB s n ratio. Ambar Cascom Ltd 0926 434141

12 bit A-to-D converter. Comlinear CLC925 is a 12 bit converter with a conversion rate of over 10 million samples/s. It has a differential linearity of 0.5LSB and in-band harmonic distortion of –70dBc at 5MHz and 72dBc at 2MHZ. Anglia Microwaves Ltd 0277 630000

Development and evaluation

V25 development and evaluation. This V25 D and E system allows applications to be developed on the NEC V25 processor using a PC, together with the Hexatron "Appcom" environment. Hexatron Ltd 0462 675530

General microprocessors

32 bit processor board. The CC118 works in hostile conditions and is a 32 bit 68020 processor, with an optional 32 bit 68881 floating-point co-processor, both working at 16MHz. The internal bus is 32 bits wide and attaches to up to 4 Mbyte of on board eprom for application software and 1 Mbyte of zero wait state ram for data. Compcontrol Ltd 040 124955

Interfaces

12 bit data acquisiton. A complete 12 bit system, the DAS862 or 863, is packaged in a 1in square leadless chip carrier or 1.1in pin grid array. It comprises an input multiplexer and instrumentation amplifier with selectable gain, a sample-and-hold amplifier and an A-to-D converter with a microprocessor interface and tri-state buffers. Microelectronics Technology Ltd 084468781

The XR-511 is a high speed, **low noise head interface** IC for hard-disc drives and the XR-541 a disc-drive pulse detector IC for use with RLL and MFM coding schemes. XR-511 performs both read and write and is compatible with 3.25 to 14in multi-platter drives. XR-541 is for application in Winchester disc drives and removable cartridge drives. Microlog Ltd 04862 29551

Microwave devices

Comb generator. The FEI A9G series step-recovery diode coaxial comb generator provides a spectrum of pulses from 0.1 to 18GHz of 120ps width at a rep. rate equal to that of the drive signal. Anglia Microwaves Ltd 0277 630000

Crystal oscillator

Ovened oscillator. Perhaps the smallest oven-controlled crystal oscillators yet developed, Oscilloquartz 8760 VC-OXCO devices are about a quarter of the size of traditional types. Phase noise spectral density at 10Hz and 100Hz is –70dBc and –105dBc respectively. Frequency range is 10MHz to 24MHz. Stability from –30deg C to 70deg C is 1 part in 10^7. Chronos Technology Ltd 0494 716146

ECL clock oscillators. The Vectron CO-450 hybrid dip ECL clock oscillators cover the range 5MHz to 400MHz. They provide complementary 10k ECL compatible outputs with a supply voltage of –4.5VDC or 5.2VDC. Standard stability from 0 to 70 deg C is 25 p.p.m. with a higher-stability option. Lyons Instruments Ltd 0992 467161

Surface-mount crystals. The Mtron SX2550P series combine advanced strip AT-cut technology with high-temperature epoxy packaging. The series covers microprocessor frequencies between 4MHz and 24MHz with a frequency tolerance of 50 p.p.m. at 25 deg C and a stability of 100 p.p.m. maximum. Quartet Technology Ltd 01-449 2700

Hz Technology Inc. GFS203 **temperature-compensated crystal oscillator** is 18.5mm by 12.5mm. It is available in the range 5-20MHz to a tolerance of 3ppm over –30 to +60 deg C. Stability with voltage variation is 0.5ppm max. for a supply change of 0.25V. Total Frequency Control Ltd 09066 5513

Programmable logic arrays

High-density 24-pin pals. PALCE29M16H and MA16H high-speed electrically erasable c-mos pal devices for glue and general-purpose logic replacement in TTL and c-mos systems. Advanced Micro Devices (UK) Ltd 04862 22121

Reprogrammable c-mos. The Cypress Semiconductor PAL C 22V10, which uses second generation c-mos PAL architecture, incorporates a programmable macro cell and draws 55mA in the low-power L version. The device has 22 inputs and 10 outputs, each of which is individually specified. Pronto Electronic Systems Ltd 01-554 6222

Power semiconductors

High-voltage, high-speed bridge driver. Bridge driver IR2110 is a monolithic power IC designed as a high-voltage, high-speed dual driver to drive the gates of a pair of n-channel power mosfets or insulated-gate bipolar transistors. Hitek Electronics Ltd 0223 213333

HEXFETS for automotive electronics. The IRL family of HEXFET power mosfets reduces the cost and complexity of electronics in cars. All devices in the family are driven directly from logic and provide an alternative to smart-power ICs. International Rectifier Ltd

Power mosfets. With a low supply current of 2.5mA and 4 ohm output impedance, the Maxim dual power mosfet drivers, MAX 626/627/628 turn large power mosfets on and off quickly. They operate from 4.5V to 18V and are compatible with TTL and c-mos input signal levels. Outputs drive in- with rise and fall times of 20ns. Thame Components Ltd 084421 4561

Standard logic circuits

Analogue switches. Three analogue switches, DG421, 423 and 425, with on-board data latches, are silicon-gate devices with on-resistances of 40 ohms and leakage currents of 0.25nA maximum. Siliconix Ltd 0635 30905

Task oriented processors

STDbus dual-axis indexer. STD 22 intelligent dual axis indexer allows users of STD computers to implement low-cost motion control for microstepping drives. It supports drive/motor resolutions of up to 50 000 steps/rev and employs ASCII commands, allowing the use of high-level languages such as Basic. Parker-Digiplan Ltd 0202 690911

Colour lookup table. IMS G178 from Inmos integrates the function of a colour lookup table, RGB D-to-A converters, microprocessor interface and display driver. The D-toAs can be switched for either six or eight-bit resolution and pixel rates of up to 80MHz are supported. Rapid Silicon 0494 442266

PASSIVE EQUIPMENT

Passive components

EMI filters. The ST range of miniature EMI filters is designed primarily for pc wer supply application. They provide high attenuation over the range 10-100MHz and are available in capacitance values of 270pF to 22 000pF. The filters are rated at 16, 25 or 50V and 7A maximum. ECC Electronics (UK) Ltd 0628 810727

High-voltage resistors. These high-voltage high-value resistors have operating voltages from 1 to 40kV and resistances from 1kilohm to 1000megohm, with tolerances of 0.5% to 10%. The thick-film process confers low inductance and the voltage coefficient of the top two models is 0.2 p.p.m./V. Menvier Hybrids Ltd 0295 56363

Crystals. As replacements for standard M-tron crystals over the 3.579545 to 20MHz band, M-tron ATS-49 series crystals offer a maximum frequency tolerance of 50ppm at 25 deg C and a stability of 50ppm. Quartet Technology Ltd 01-449 2700

Snap-in electrolytics. The Philips Type 054/055 series of "snap-in" capacitors offers a capacitance range of 47 to 33 000 microfarads, with a tolerance of 20%, in ratings of 10V to 385V. RR Electronics Ltd 0234 270272

Multi-capacitor arrays. The SIP series of epoxy-coated ceramic capacitors is available in NPO, X7R and Z5U dielectrics, with tolerances of 5%, 10% or 20%. Capacitance range is 10pF to 220000pF. Vitramon Ltd 06285 24933

High-density backplanes. Dage has developed custom backplanes which overcome size and mating-force problems posed by large Eurocard DIN connector buses. They are AMP's HDI press-fit PCB connectors and offer up to 564 connections on a standard triple-height Eurocard. Dage (GB) Ltd 0296 393200

Circuit protection

Resettable over-current protection. The MultiFuse range of devices is a series of positive temperature coefficient solid-state components which behave as fuses under over-current conditions but which return to a low-resistance state when cooled below a trip point. They will also trip under over temperature conditions. Bourns Electronics Ltd 0276 692392

The XR-1543/2543/3543 **supervisory circuits** contain the functions needed to monitor and control the output of a power supply, including over-and under-voltage sensing and current limiting, with provision for external crowbar triggering. The internal reference is accurate within 1%. Microlog Ltd 04862 29551

Displays

Digital indicator/controllers. Models D450, 350 and 351 display the signals from analogue measuring instruments in several units, for example those of pressure, load, displacement or torque. Control Transducers 0234 217704

Information display modules. These 16 by 16 dot-matrix displays run at video speeds (20MHz) and are available in mono and tricolour led combinations. They are made in 3.5 and 8mm dot sizes. Panasonic Industrial (UK) Ltd 0753 824851

Instrumentation

Power meter. Boonton's Model 4220 low-cost power meter occupies 3 5in half-rack space and can be used over the range 100kHz to 110MHz It accepts interchangeable power sensors of coaxial or waveguide, diode or thermocouple types, for 50 or 75 ohm operation Sensors cover the range – 70dB to 30 dBm Aspen Electronics Ltd 01-868 1311

Real-time clock. Real-time clock unit 10374 is a self-contained unit accurately to retrigger up to 16 programmable pulsed outputs at set times up to 64 times during a week Eeprom storage for event time settings ensures data security during loss of power Cescom Electronics Ltd 01-534 7613

When used with an IBM PC or compatible, this **logic analyser** presents information and user prompts simply It has 24 input data channels, can operate at sample rates of up to 100MHz and has an acquisition memory of 8K Componedex Ltd 0908 322177

Digital chart recorder. The PL16 recorder converts almost any printer into a multi-channel recorder – monitoring up to 16 channels of analogue data The choice of characteristics includes number of channels, sensitivity of each, plot type, speed and printer type, all set up using keypad, LCD and internal menu Eidawn Biosensors Ltd 0792 295573

Analogue/digital oscilloscope. The ITT OX750B oscilloscope is a dual-trace instrument with digital storage capability Any event from 100 to 200 microseconds per division can be captured and displayed The preceding instant's trace is retained to allow the origin of the event to be seen Analogue bandwidth is 20 MHz. Feedback Instruments Ltd 0892 653322

PC-instrument counter/timer. This multi-channel instrument is intended for the automatic evaluation of power supplies and is an add-on board for Interpro's Micro-Series ATE system Applications include adjustment of switching oscillator, checking power-up time or monitoring recovery times Interpro Systems Ltd 0425 471421

Logic analyser. This PC-based instrument, the Pc/La, is a 32-channel, 100MHz analyser with 32 data channels and 4K samples of buffer per channel It is on a full-size PC expansion card with a test prod and clips Multi-way branch and loop triggering is provided MA Instruments Ltd 0822 853585

Time interval analyser. The TIA 3100 from Kode measures bit shift, margin and error rate with 100ps resolution Maximum sampling rate is better than 1MHz and the instrument will detect faults in tape and disc drives, whether Winchester, floppy or optical Time interval measurement range is from 5ns to 440ms. Steatite Insulations Ltd 021 634 6888

Signal-processing analyser. The Tektronix 3052 digital spectrum analyser has a 2MHz real-time signal-processing capability The system includes a high-resolution colour monitor with disc drives and is operated from a detachable front-panel/keyboard Thirteen frequency display spans cover 1 kHz to 10MHz or, with downcounters, up to millimetric frequencies. Narrowest resolution is 1 25Hz in the 1kHz span Tektronix (UK) Ltd 06284 6000

V/I/R calibrator. This portable calibrator provides voltages from 10nV to 100V, current from 100nA to 100mA and resistance from 10 milliohms to 10 kilohms at accuracies within 0.005% Resolution is 1 p p m and control is digital, enabling output to be adjusted in steps of 0 999% Time Electronics Ltd 0732 355993

Materials

Ferrite RF chokes and filters. SEI/Thomson announce a grade of ferrite material for use in mains RFI chokes and filters T8 ferrite combines a permeability of 3 500 with a saturation flux density of 0.48 Tesla Salford Electrical Instruments Ltd 0706 67501

Power supplies

Triple-output DC-DC converters. Known as UW Triples, Models 48T5 12UW and 48T5 15UW accept any DC input between 18 and 72VDC and provide three DC outputs, a single 5V rail at 800mA; a positive/negative supply at 185mA; or positive/negative 15V at 150mA Calex Electronics Ltd 0525 373178

Voltage regulator for micros. SGS-Thomson's TEA7105 is a voltage regulator suited to microprocessor-based digital systems Reset, watchdog, store and on/off functions are included, enabling the activity of a dedicated microprocessor to be controlled Impulse Electronics Ltd 0883 46433

DC-DC converters. Single and dual-output mosfet converters with an output power of 20-150W, the KIP series use switching techniques at a frequency of 1MHz Efficiency is about 84% Kingslo Ltd 0635 32585

DC power supplies. The Condor medical DC power supply range now comprises 18 single-output, 6 dual-output and 2 triple-output models, providing power to 50W and voltages from 2 to 28V. The units are of the linear open-frame type and meet the VDE 0871 level B RFI standard Gresham Powerdyne 0722 413080

Radio communications products

Miniature VCO. The MQC500 series of voltage-controlled oscillators operate from a supply voltage of 5V, have a current consumption of 5mA and measure 20.1 by 12 5 by 7 5mm overall They provide a minimum output of – 2dBm, a s n ratio of 45dB and carrier-to-noise ratio of 75dB Murata Electronics (UK) Ltd 0252 522111

Mobile radio. Fleetmaster is a compact, dash-mounted, FM two-way radio operating on up to six fixed, crystal-controlled frequencies in the ranges 66-88MHz and 156-174MHz The RF performance meets current UK and CEPT specifications Pace Communications (UK) Ltd 0489 788122

Switches and relays

Dil relay. The ITT MT2 is a dual in-line relay which, with two changeover contacts and a nominal power consumption of 150mW at 20 deg C, has a high dielectric strength and can switch currents of up to 1 25A ITT Multicomponents Ltd 0753 824212

Transducers and sensors

Thermocouple trip amplifier. Internal hysteresis ensures positive switching and immunity to noise, whilst cold-junction compensation is implemented close to the input terminals to eliminate the need for large isothermal blocks The devices can be wire-Ored to drive a common load Klippon Microsystems Ltd 0732 460066

Hand-held character reader. The Soricon Pencilwand is designed for selective data entry and is capable of being passed across machine printed text for entry to PC XTs, ATs and compatibles Package includes "wand" full-size PCB, diskette and manual Bar-code software is available Micro-Marketing (Electronics) Ltd 06285 29222

Pressure transmitter. This is a device for power-loop applications, where two-wire telemetry systems are used It is available in pressure ranges from 0 to 100 p s i at an accuracy within 1% or up to 10 000 p.s i at better than 0 25% The BP16E interfaces with all types of 4-to-20mA current-loop instruments Pioden Controls Ltd 0227 463641/463072

Load transducer. The UFI load transducer has a sensitivity of 4mV V with an accuracy better than 0 5% and an overload capacity of 2 5kg in all ranges The device measures steady and fluctuating tensile or compressive forces in the range 25kg to 1000kg with an armature displacement of 0 05mm Pioden Controls Ltd 0227 464641/463072

COMPUTER

Computer board level products

Faxcards for PCs. New versions of the C-Fax Plus and C-LANFax add-on faxcards for IBM PCs and compatibles handle incoming multi-page fax messages much more quickly Each page is individually converted and immediately displayed on screen C-Fax Plus provides full Group 3 facilities to CCITT standards Communicate Distribution Ltd 01-390 6802

DSP board. A VME digital signal processing board based on the INMOS IMS A100 DSP is available from T-Cubed The VME-T3A4 is the first in a range of VME products for low-cost signal and image processing application Hawke Systems Ltd 0753 686686

Data communications products

Transient protection for modem lines. The MP modem protector from General Semiconductors is designed to guard modem lines from transients caused by lightning, inductive switching and electrostatic discharge The units will clamp transients up to 10kV and 2 5kA per wire in less than 10ns Hunter Electronic Components Ltd 0628 75911

Mass storage devices

200 Mbyte 3.5in disc drive. Swift is a range of 3 5in drives which is available in capacities of up to 200 Mbytes (unformatted), with an average seek time of 15ms The drives can be used with a industry standard interfaces such as SCSI, EDS[illegible]06 Rapid Systems 0494 450244

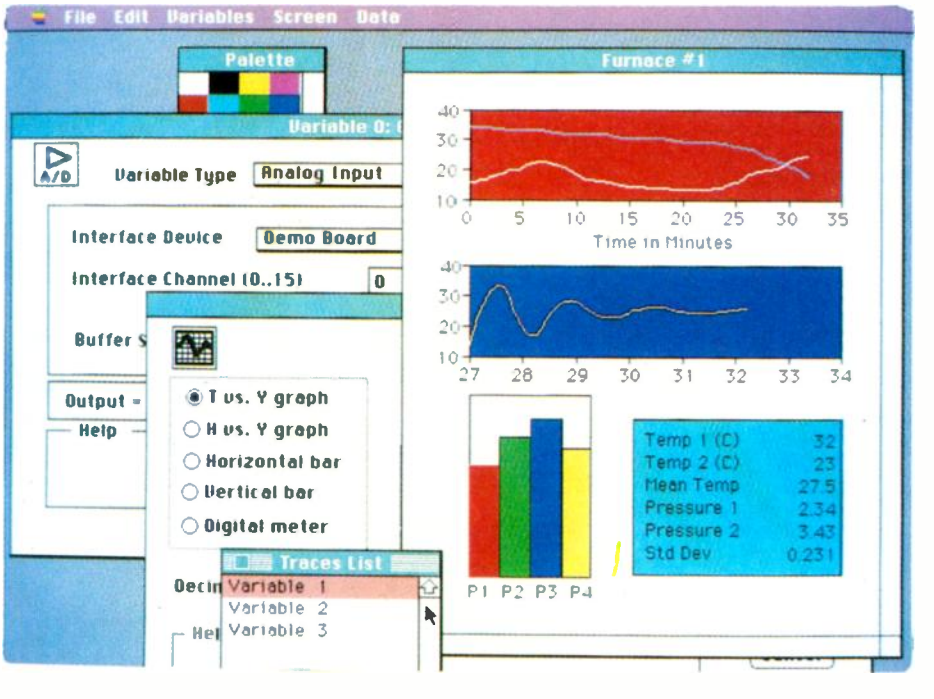
Software

Labtech Notebook. The Apple Macintosh version of Labtech Notebook software for data acquisition, monitoring, control and analysis runs on Apple Macintosh II, SE or MacPlus computers Data acquisition interface cards are available from several sources Adept Scientific Systems Ltd 0462 480055

Logging and display. A software package enables PCs and compatibles to log, store and graphically display data collected from the AIP-24 analogue input card It can sample up to 24 channels at up to 3500 samples per second into a 64Kb ram buffer Blue Chip Technology 0244 520222

Cadnetix has introduced a series of enhancements to existing CADM **software for SMT** These include alternate shapes, multiple clearances, fixed via grid, inner pad and via removals, automatic stringer generation and a macro capability Cadnetix Ltd 0793 513400

Low-cost GPIB interface. Asystant GPIB provides a menu-driven control package to control GPIB instrumentation Data is displayed in a number of ways, including bar charts, graphs and windows Mathematical facilities include statistics, polynomial and differential equations and array and matrix operations Roalan International 0202 86 1512



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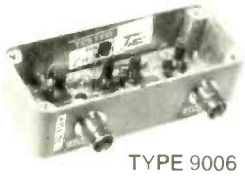

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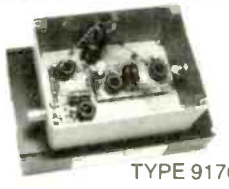

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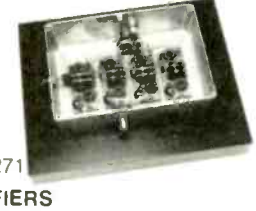

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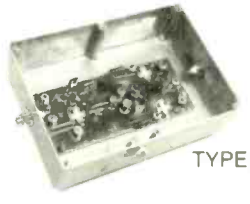

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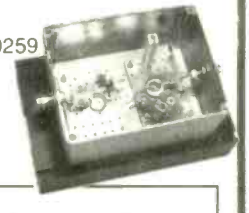

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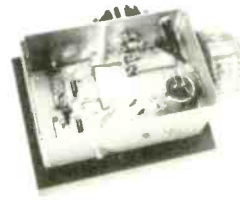

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The intriguing ball-bearing motor

Whether or not one can accept the author's contention that it delivers energy produced from nothing, the novel electric motor he describes certainly deserves to be better known.

STEFAN MARINOV

It is almost unknown that if direct or alternating current passes through the ball-bearings of an axle, it is set in rotation. In the few papers where this effect is discussed, the torque is explained as an electromagnetic effect. Yet the torque is due to thermal extension of the balls in their bearings at the points of contact with the bearing races.

The arrangement of the simplest ball-bearing motor is given in **Fig.1**, where the inner races rotate. With the same ball-bearings, a bigger torque can be obtained by rotating the outer races. In such a case the axle must be made of two electrically insulated parts, and the current goes through a metal cylinder connecting the outer races of both ball-bearings. Such are the small and big ball-bearings motors presented in **Fig.2**.

I have established that the ball-bearing motor is *not* an electromagnetic motor but a thermal engine. Here the expanding substance leading to mechanical motion is steel, while the expanding substance in all thermal engines used by humanity is gaseous. There

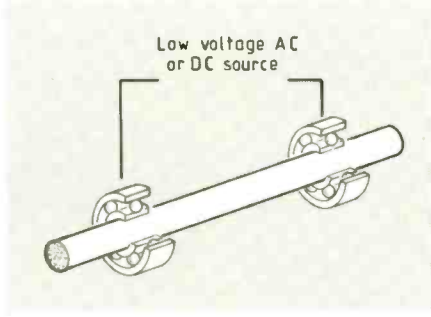

Fig.1. The ball-bearing motor rotates in either direction, on AC or DC supplies. Its mode of operation is thermal, not electromagnetic.

is, however, another much more important difference: the motion in the conventional thermal engine is along the direction of expansion of the heated substance, while in the ball-bearing thermal engine it is *at right angles* to the direction of expansion of the heated substance. Consequently, in gaseous thermal engines, the gas cools during the expansion and the kinetic energy acquired by the "piston" is equal to the heat lost by the expanding gas. This is *not* the case in the ball-bearing motor. Here not the whole ball becomes hot but only that small part of it which touches the race, at a "point contact" where the ohmic resistance is much higher than the resistance across the ball. Only this small "contact part" of the ball dilates; and the dilatation is very small, only a few microns. (Of course, I have not measured the dilatation, I only *presume* that it is a couple of microns.) Since the balls and the races are made of very hard steel, a slightly ellipsoidal ball produces a huge torque when one of the races rotates with respect to the other.

Usually a push is needed to start the ball-bearing motor. However, on occasions it does start spontaneously (with a greater probability at greater bores) because the surface of the races is not absolutely smooth. With absolute smoothness and geometrical perfection, spontaneous starting is im-

Great balls of fire

The contents of Dr Stefan Marinov's travel-weary holdall did little to dispel the scepticism which greeted the man and his theories during a visit to our editorial offices. We politely listened to a rambling discourse on ball-bearing electric motors which rotated without magnetism and provided work in defiance of energy conservation theory. Dr Marinov unburdened himself as a man proselytising a deeply held yet widely ridiculed conviction.

The two ball races, one set into each end of a tube, didn't look to be the starting point from which new theories are forged. Neither did the thin PVC-covered wire connecting up to the blocks at each end of the tube supporting the ball race inner sections. "Stefan, how much current do you need to make the races turn... Would 5A be enough?"

"No, you need a lot more than that".

"25A?..."

"No. Much more."

"How much more?"

"Have you got a car battery?"

"Only the one fitted in my car."

"Get it. I show you..."

"Stefan, if you connect up a car battery to your machine using those wires, the ball races will present an almost perfect short circuit and the wire will vaporise in a puff of acrid smoke..."

"They get warm, sure. But I show you. Where is your car?"

"In the multi-storey..."

But Dr Marinov never heard the rest of my protests. He was already down the corridor and halfway out of the building. I headed him off at the revolving doors in the lobby.

"Stefan, the multi-storey is no place to advance science. Let's see if we can borrow a battery from the motor transport department."

We set off across the road, Marinov clutching his holdall. I went upstairs to get permission from the garage manager. When I returned Dr Marinov was nowhere to be seen. I went into the garage to enquire of the duty mechanics the whereabouts of my Bulgarian friend.

"Have you seen a foreigner with a battery fixation?"

The huddle of mechanics pointed to a figure crouched over a stack of batteries in a corner of the garage. The figure looked up without surprise.

"I think this should work. Put your thumb on the bearing tube and, when I connect up to the battery, give it a flick."

I looked doubtfully at the battery, the machine and the wires in turn.

"I'm telling you, Stefan, those wires will simply melt." He didn't answer. He forced the bare ends of the wires hard against the battery terminals. There was a shower of sparks and an eruption of smoke from the blistering cable ends. I gave the tube a flick. It took up a life of its own which all but had the skin off my thumb. The tube connecting the bearing outers spun up to what must have been at least 1500 rev/min before the connecting wire, unequal to the enormous current, disintegrated.

"You see it turn?"

I looked at the burgeoning friction burn on my thumb.

"Yes."

I also looked at the acrid blue haze of PVC smoke which was rolling across the floor towards the group of curious mechanics.

"Your bearing motor certainly works but I shall need a bit more convincing about it being a net producer of energy."

Dr Marinov simply gave me a look which suggested that all his efforts had been in vain.

Frank Ogden

possible.

During rotation the ball's "bulge" moves from the one race to the other, the local overheating is absorbed by the ball and the radius of the "bulge" becomes equal to the radius of the whole ball. At the new point of contact, when current passes and ohmic heat is produced, the radius of the contact point becomes again bigger than the radius of the whole ball and again a driving torque appears. Thus, as a result of the mechanical motion, the ball is *not* cooled; and consequently, in the ball-bearing thermal engine, heat is *not* transformed into kinetic energy. The whole heat which the current delivers remains in the metal substance of the machine and increases its temperature. If the ohmic resistance between balls and races is the same both at rest and in rotation, the heat produced and stored in the metal of the machine will be the *same* at rest and rotation. This resistance, however, increases in rotation; but with further increase of the velocity the increase of resistance is very slight.

I established that the ball-bearing motor produces the same amount of heat at rest and rotation in the following manner. I measured for a definite time the temperature increase in a calorimeter in which the motor was maintained at rest, applying a tension U and registering the current I. Thus the resistance of the whole motor was $R = U/I$. Then I started the motor and applied a tension U′ such that at the new resistance R′ the current $I' = U'/R'$ was such that $UI = U'I'$; i.e., in both cases I applied exactly the same electric power. According to the energy conservation law, in both cases the temperature increase of the calorimeter had to be the same, as in both cases the same amount of electric energy was put in the machine.

I recorded, however, that in the second case the temperature increase of the calorimeter was higher. Thus I concluded that in both cases the ohmic produced heat was the same; however in the second case there was also heat coming from the friction of the rotating ball-bearings. The temperature increase in the second case was about 8%, while the mechanical energy produced was about 10% of the input electrical energy.

One can see immediately that the ball-bearing motor has no *back tension* because there are no magnets, and the magnetic field of the current in the "stator" cannot induce electric tension in the metal of the "rotor".

Thus the firm conclusion is to be drawn that the mechanical energy delivered by the ball-bearing motor is *produced from nothing*, in a drastic contradiction to the energy conservation law.

With a direct current supply, the ball-bearing motor can rotate either *left* or *right*. Thus it cannot be an electromagnetic motor, since a DC electromagnetic motor rotates only in one direction, with a given direction of the current. The ball-bearing motor rotates with DC as well as with AC. With a greater current it rotates faster. It is interesting to note that the resistance of the ball-bearing motor depends on the current, and for higher current it is *lower*. If the current doubles, say, the applied tension increases only, say, 1.3 times. Here I wish to avoid any confusion between the increase of resistance because of the increase of the rate of rotation, and the decrease of resistance because of the *increase* of *current*; although, obviously, a higher current leads to a higher rate of rotation. The torque disappears if the ball-bearings are replaced by box-bearings.

At equal applied electrical powers and equal number and size of the balls (i.e., at equal resistance), the torque is bigger for a ball-bearing with bigger bore. A ball-bearing with two times bigger bore has two times bigger torque. **Fig.2** shows two ball-bearing motors with a small and a large bore which have almost equal ohmic resistances (of course, the mechanical friction of the bigger motor is greater). By touching both motors, one can immediately feel the difference in their torques. The bigger ball-bearing has greater number of balls and consequently a bigger torque; however, its current (and power) consumption are higher.

IN A BULGARIAN PSYCHIATRIC INSTITUTION

In 1966 I was imprisoned in a psychiatric clinic in Sofia and 'cured' by horse-doses of neuroleptics (Mageptil), of my unorthodox political thinking. Also imprisoned in the institution to be forcibly cured was another seemingly absolutely normal man. He was a very able mechanic who, refusing to work for a salary in a state plant, had executed special work on his own lathes and milling tools installed in his living room and the apartments of relatives. He had earned good money, but evidently the envy of his neighbours had brought him to the loony-bin to be purged of his vicious individualistic behaviour.

This man asked me once in the toilet (as a very dangerous lunatic I was kept locked the whole day in isolation and watched by a policeman, and so it was only in the toilet that I could speak with other human beings), "Well, Stefan, if you are a physicist, explain why an axle on ball-bearings rotates when current flows through it".

I could not give an answer, and the mechanic shook his head: "What are the professors in the universities teaching, if they cannot explain such a simple thing?"

At that time I did not know that this simple experiment was unknown to the professors; the first publication on this effect[1] was to appear a year later. *Ergo*, when this extremely important effect was discussed by the idiots in the toilet of a Bulgarian psychiatry, it was not yet registered in the scientific annals of the physical world.

Milroy[1] describes the effect without giving an explanation for the torque. Eleven years later Gruenberg[2] repeated Milroy's experiment and tried to give an explanation. Although he used very sophisticated mathematics, Gruenberg's starting hypotheses are physically nonsensical. A further three years later, Weenink[3], in a big article proceeding from the same nonsensical starting hypotheses, drew the conclusion that "the non-zero torque in first order found by Gruenberg is shown to be due to an algebraic error" (p.171)."

Another theoretical paper dedicated to the ball-bearing motor was published a further two years later by van Doorne[4] who tried to explain the torque by electrostatic forces, but concluded that "this torque, however, is too small to keep a ball-bearing motor running" (p.327). In 1980 A. Mills[5], in a popular journal, showed a photograph of a ball-bearing motor constructed by him and reported almost the same effects as Milroy and Gruenberg. Not once, though, was Mills able to self-start the motor, though this can be done very often (10% probability) when the ball-bearings have a greater bore.

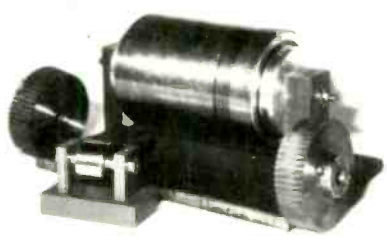

Fig.2. Small and large ball-bearing motors. A low-voltage, high-current supply is suitable.

IMPROVING PERFORMANCE

Methods of improving efficiency in the ball-bearing motor include the following:

- The use of balls which are harder and where a smaller amount of heat leads to larger thermal extension. We know that normally a harder solid body has a lower coefficient of thermal dilatation, so that one has to find the optimal solution which nature offers.
- Tighter ball-bearings have a better pushing force. However, at the same time they will have more friction. A compromise is needed. But even if friction is very low, there is always a maximum velocity which the motor cannot surpass. At this maximum velocity, heat from the "bulge" cannot be absorbed by the ball, and the ball retains more or less a spherical shape. It is obvious that the maximum velocity is higher for larger balls.
- The driving force is higher for bigger bores, as the curvature of the races is less.
- The driving force is greater for bigger balls, as their curvature is less.

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Dr Marinov is at the Institute for Fundamental Physical Problems, Morellenfeldgasse 16, A-8010 Graz, Austria.

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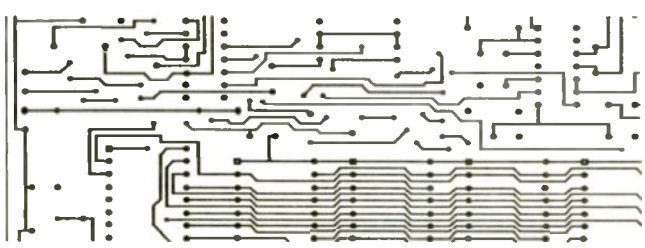

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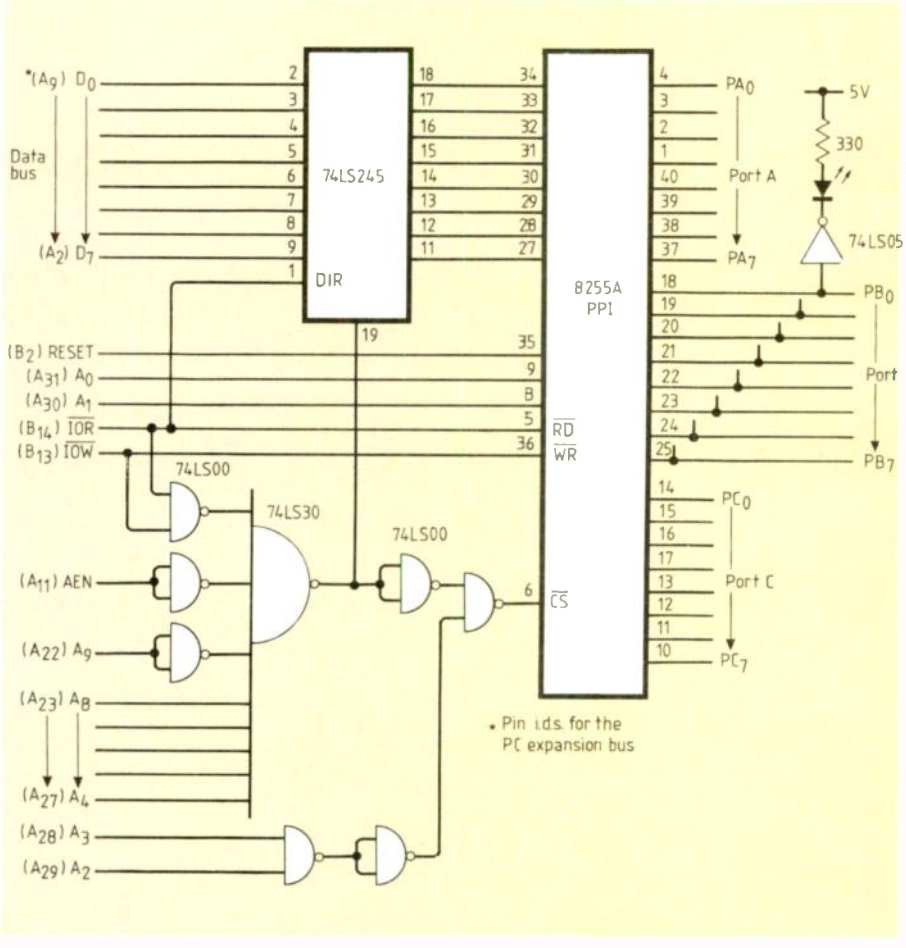
An 8255 interface chip controls the three eight-bit ports designated A, B and C; all three are bidirectional. Signal $\overline{IOR}$ determines the direction of the LS255 bus transceiver and address decoding, carried out by Nand gates, places port A at $1FC_{16}$, port B at $1FD_{16}$ and port C at $1FE_{16}$. Adding the LS05 and leds allows the port lines to be monitored; this small routine sets bits on port B according to input data.

```
10 OUT 1FFH, 90H
20 INPUT A: OUT 1FDH, A
30 GOTO 20
```

A.J. Crispin
Leeds



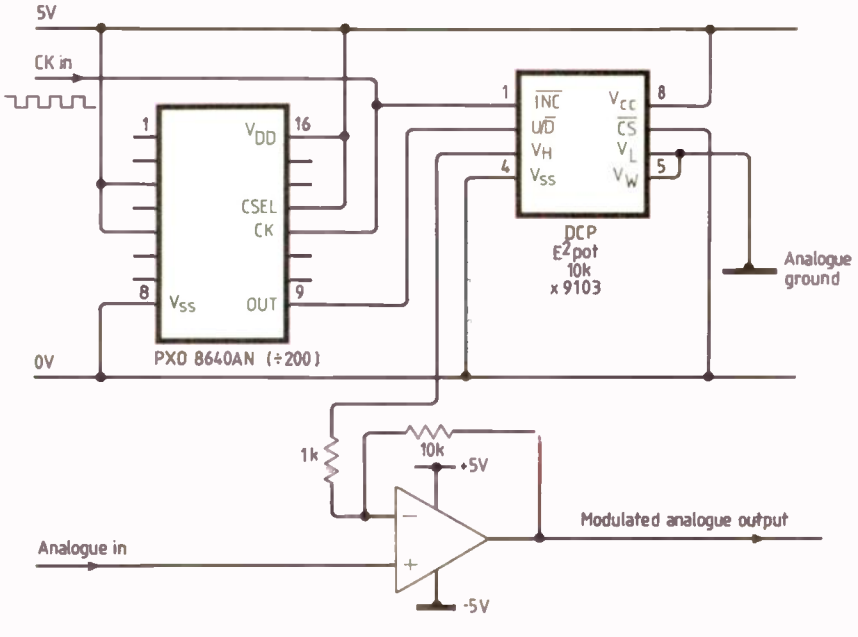
Amplitude modulator using electronic potentiometer

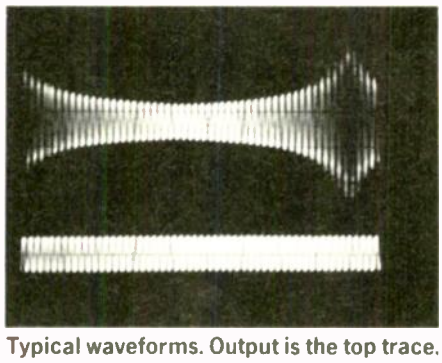
I designed this amplitude modulator for signals of less than 1Hz but it works satisfactorily at much higher frequencies. Three main elements of the circuit are a digitally-controlled potentiometer, a programmable crystal oscillator and a variable-gain op-amp.

A TTL-level clock feeds the external clock input of the programmable crystal oscillator and the increment input of the digitally-controlled potentiometer. Division ratio of the oscillator is set at 200 so the up/down input to the potentiometer changes direction every 100 cycles.

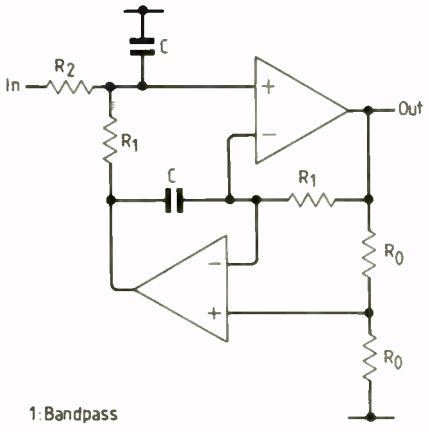
Since the digital potentiometer is configured as a simple resistor, gain, and hence modulation depth, of the amplifier varies at a rate determined by the clock frequency. The potentiometer is available in three versions, 10k, 50k and 100kΩ.

T.G. Barnett
London



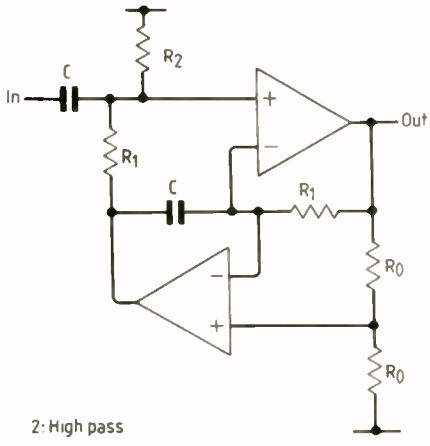


Typical waveforms. Output is the top trace. Input in the bottom trace is a 1kHz sine-wave at 0.5V pk-pk, and the clock frequency is 4kHz.



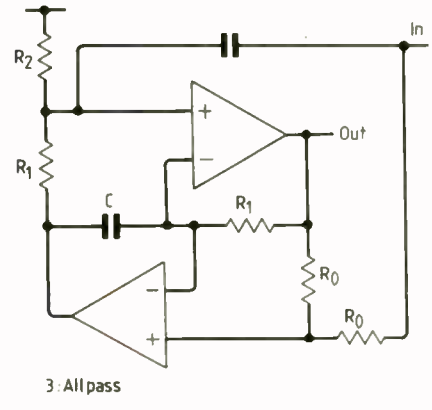
1: Bandpass

$$\frac{V_{out}}{V_{in}} = 2\frac{sCR_1^2/R_2}{K}$$



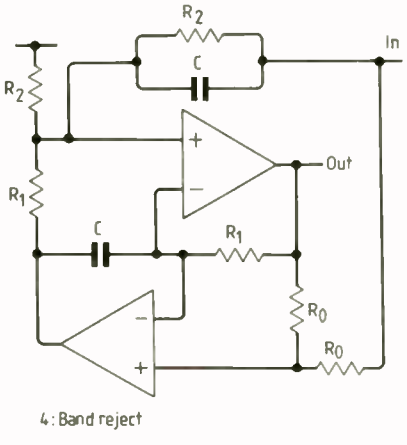
2: High pass

$$\frac{V_{out}}{V_{in}} = 2\frac{s^2C^2R_1^2}{K}$$



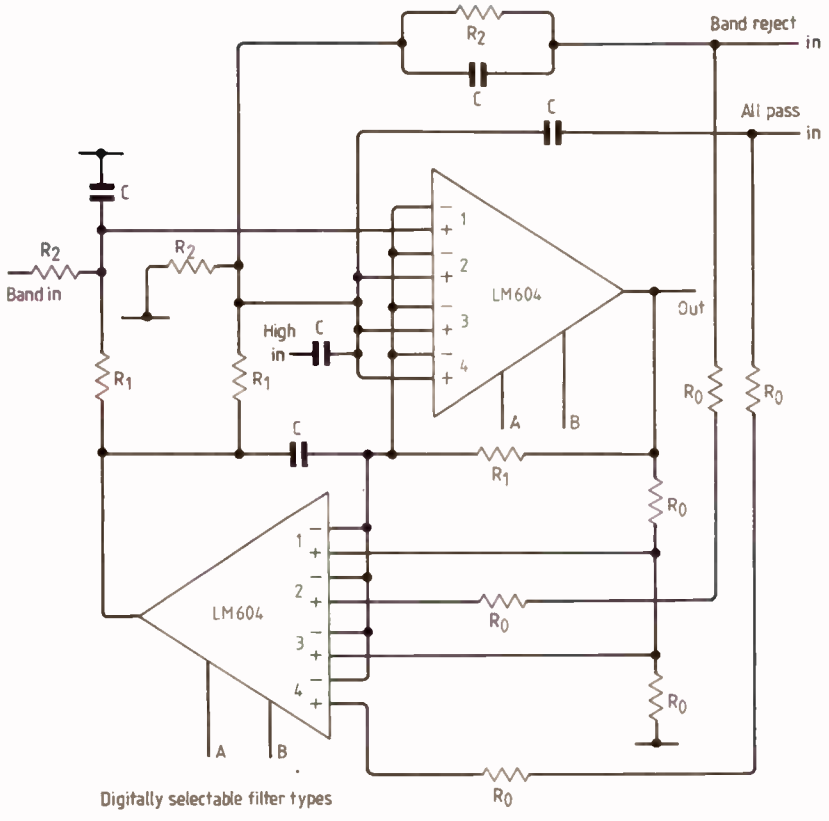
3: All pass

$$\frac{V_{out}}{V_{in}} = \frac{1+s^2C^2R_1^2}{K}$$



4: Band reject

$$\frac{V_{out}}{V_{in}} = \frac{1-sCR_1^2/R_2+s^2C^2R_1^2}{K}$$



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$$Q = R_2/R_1.$$

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Scrambling television

Eurocrypt and Eurocypher are the latest in a series of conditional access systems used for satellite and cable transmissions in Europe. Frank Huntingford of Hi Tech Xtravision reviews the principles on which television scrambling systems work.

Satellite broadcasters are now adopting conditional access systems which offer a level of security much higher than anything seen previously in Europe. Much is at stake: a subscription to Sky Television's pair of pay-tv channels will cost more than twice what viewers now pay for their terrestrial licence fee, which supports the BBC's entire domestic radio and television output. For other pay-tv channels, viewers will have to pay still more.

The temptation to would-be pirates is obvious. Receiving hardware for the new conditional access systems will soon be installed in millions of homes across the continent, affording interested parties the opportunity to mount an assault on these systems on a scale which has never been possible with other high-security hardware – for example, that used by banks for keeping intruders out of our personal accounts. The cut-and-rotate scrambling systems adopted by the new broadcasters are of daunting, seemingly impenetrable complexity. But if the future funding of good-quality television broadcasting is to depend on them, they need to be.

Four analogue encryption systems widely used in Europe are described here. Many others are used in America, but these seem unlikely to cross the Atlantic. The decoders are illustrated only in their most basic form: much extra complexity may be needed in the decoder to distinguish a legitimate signal from real garbage.

SAVE

This system is used by Premiere, the BBC and was used by the now defunct Spanish 'Canal 10'. Encryption involves inverting the video, reducing its level by 6dB and adding an interfering sine wave of approximately 95kHz.

SAVE is a fairly low-security encryption system: a watchable picture can easily be created by simply inverting the received signal, amplifying it by 6dB and filtering out the sinewave. But this filtering leads to a certain loss of video performance. A far superior method is shown in block form in **Fig. 1.**

The received signal is first amplified. A synchronous detector, forming part of a phase-locked loop locks an oscillator to the interfering signal. The output of the oscillator is fed in antiphase but at the correct level to a summing amplifier together with the amplified and non-inverted signal. The output of the summing amplifier is a descrambled video signal.

MATSUSHITA

This system is used by Filmnet, a film channel intended for the Low Countries and Scandinavia, though more than 90% of the films are in English with a variety of languages available as sub-titles on teletext (Filmet has now moved to the medium-power Astra satellite.)

The present method of encryption consists of inverting alternate fields of the signal and shifting the DC level of the blanking signal to raise the sync and colour burst signals into the active video area. This very effectively disables the sync separator in the television set or video recorder. An addition signal is transmitted on a subcarrier at 7.56MHz, which is frequency-modulated with the composite blanking signal. A further subcarrier at 7.02MHz is modulated with subscriber data information to enable or disable registered subscribers' decoders for various subscription levels.

Decoding consists of recovering the transmitted blanking information to restore the correct DC level in the blanking area, and

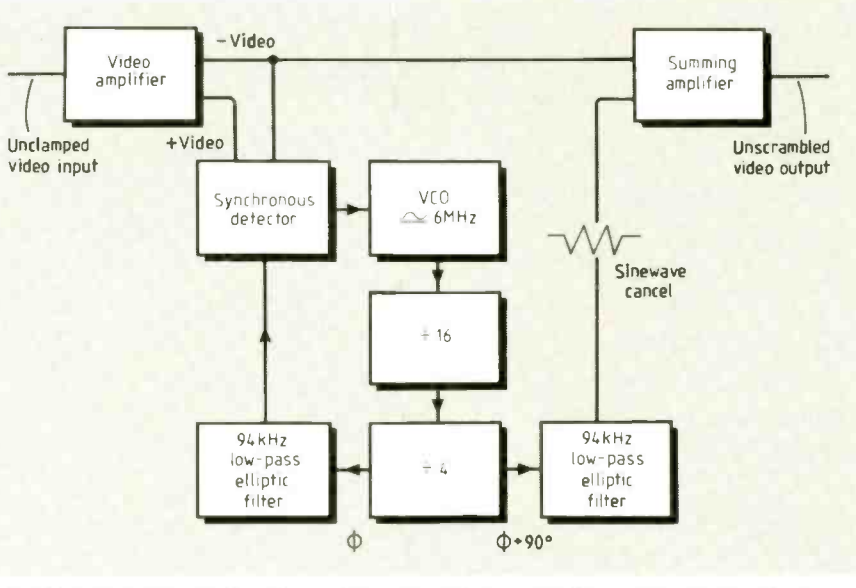


Fig.1. SAVE: decoding this low-security system entails cancelling an interfering sine wave.

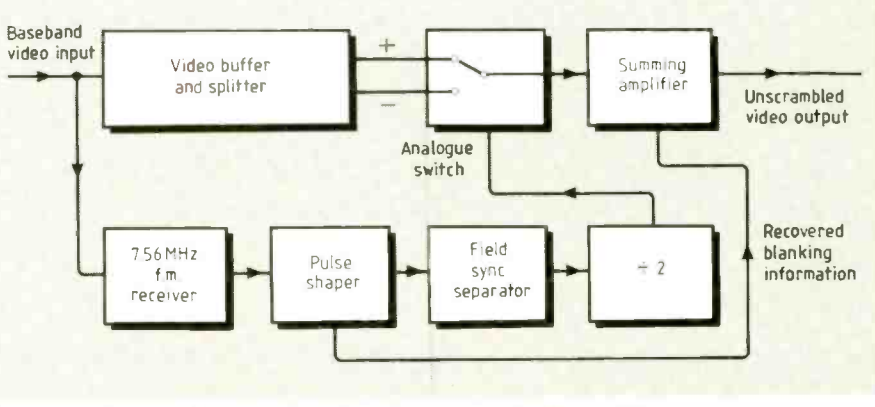


Fig.2. Decoding the Filmnet channel: in this system by Matsushita, syncs are corrupted and alternate video fields inverted.

re-inverting alternate fields (**Fig. 2**). This signal is easily derived from the field blanking information. A pulse occurring in the blanking of every fourth field enables field inversion to be synchronised at the correct polarity.

A weakness of this system is that blanking information is essentially redundant and can easily be reconstructed from the scrambled video without the complexity of a subcarrier receiver. But the system can make several tiers of encryption available at the flick of a switch – perhaps including active video inversion.

LINE SHIFTING

This system is used by the BBC for late-night terrestrial broadcasting to doctors, by *Canal Plus* in France and a growing number of other continental stations. It consists of leaving the syncs and colour burst unaltered but selectively delaying the active part of the video waveform, on a line-by-line basis. Delay time is selectable between 900ns and 1.8μs. The specific delay is controlled on transmission and reception by a predetermined algorithm. The resulting picture is recognisable (with a lot of squinting) but visually quite disturbing.

Encryption of this system is completed by scrambling the audio by frequency inversion using a single-sideband technique, with a suppressed carrier at 12.8kHz.

Decoding (**Fig. 3,4**) consists of delaying all lines to the same total – approximately 1.8ms – by using a stored algorithm in an eprom on the decoder, and recovering the audio using single-sideband detection. Addressing for the eprom is derived from a counter using line frequency as its clock and synchronised to the frame pulse.

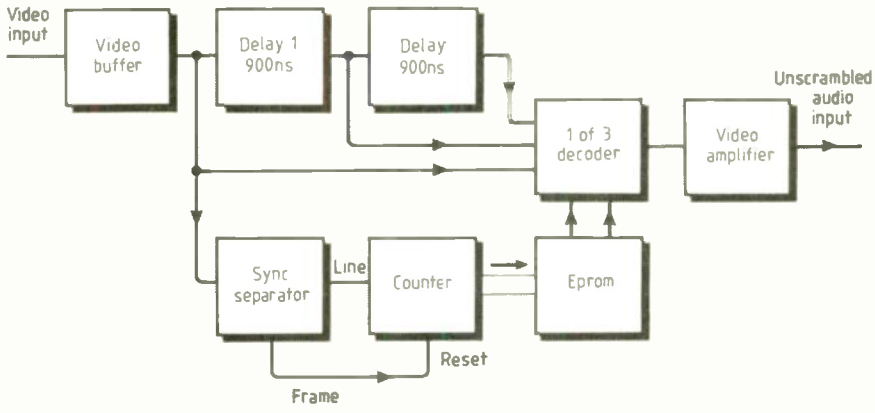


Fig.3. Line-shifting: for this system, now used during the night on BBC transmitters for programmes from British Medical Television, individual lines are delayed by differing amounts.

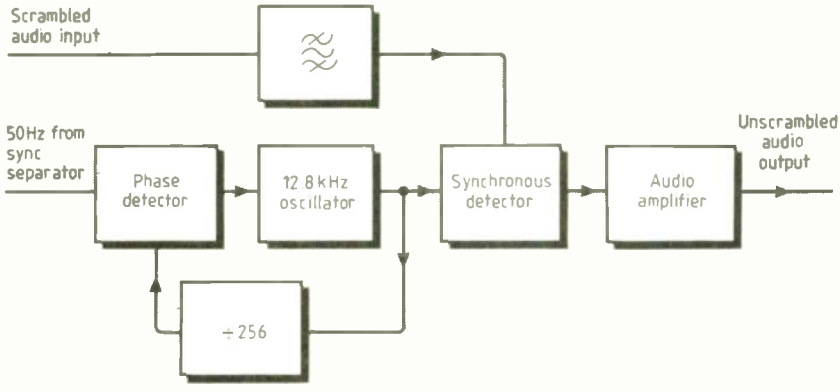


Fig.4. Line-shifting: in this scheme, the audio is made unintelligible by simple frequency inversion.

LINE DICING OR CUT-AND-ROTATE

This is the system proposed by Sky Television as Eurocrypt. It consists essentially of partioning the line into two, three or possibly more segments and interchanging the information in those segments. Cut-and-rotate is certainly the most secure analogue encryption system yet proposed for broadcasting television programmes to the public.

The cut point or points on the line and the interchange order are determined by a stored algorithm. Basic information for the algorithm is stored in a "smart card" – this is like a credit card but has rom, ram and a processor included. The card will probably give controlled serial information to the decoder and will be changed at regular short intervals, perhaps three months or less.

Hi-Tech XtraVision is at Camberley, Surrey.

It is not the author's intention, or that of his company, to encourage the infringement of copyright in encrypted television programmes.

RECEIVERS FOR SATELLITE TELEVISION

Scores of companies all over Europe are producing home terminals for suitable for Astra's 11GHz transmissions, but the list of manufacturers of 12GHz equipment for BSB's service is for the first three years restricted by BSB to just three: Ferguson, part of the French-owned Thomson group, Salora, a large Scandinavian receiver maker, and the Taiwanese company Tatung.

Ferguson, having a foot in both camps, has launched a range of receivers capable of giving access to both Astra and BSB. For Astra, a 60cm dish and receiver for Astra will be offered from late March at £300 (an 80cm version for viewers north of Manchester will cost an extra £30). Features include remote control, on-screen graphics and electronic polarization switching. Two Scart (peritel) sockets will be provided for add-on decoders. Later in the year, a further £100 will buy versions ready-equipped with a decoder for Sky Television's Eurocrypt channels.

For BSB, Ferguson will have – from September – a remote-controlled receiver with digital stereo decoder and RGB or PAL output at about £300, including a "squarial" flat plate antenna. A Eurocypher conditional access module is included.

ANALOGUE DE-SCRAMBLER

Experimental de-scrambler for the Matsushita encryption scheme.

MICHAEL GREATOREX

This analogue decoder is intended for use with more versatile receiving equipment than the Astra-only variety, i.e. that having Ku-band coverage with polarity control and a dish diameter of the order of 1m. Filmnet's original home, Eutelsat F1, gives an EIRP at the centre of its footprint of 41dBW and covers most of the UK. Astra offers a marginally stronger signal of 51dBW for the whole of Europe.

In Filmnet's Matsushita analogue encryption scheme, alternate frames contain either inverted frame syncs with non-inverted line syncs, or non-inverted frame syncs with inverted line syncs. The sense is reversed for odd and even fields. Further reversals of polarity occur randomly in bursts lasting from several seconds to a few minutes.

Several modes of operation are reported to be possible with the Matsushita scrambler and there are possibly more combinational corruptions to overcome, but during the last couple of years the decoder illustrated here has taken all that has been thrown at it.

Video and sync pulses arrive from the composite baseband signal of the satellite receiver. A phase-splitter stage provides positive and negative-going video. In switch position 1 (clear) the composite video is switched straight through. In positions 2,3 and 4, the TBA 920 horizontal combination i.c. comes into operation. This complex i.c. uses a stable PLL line oscillator to provide line syncs at pin 2. These pulses eventually control the analogue switch to allow composite syncs through to the sync separator. Field sync pulses from the separator trigger the dual D-type bistable, which switches the video polarity for alternate fields via the analogue switches and triggers the 555 timer to produce field timing. The re-formed composite video and sync signal is then de-emphasised (the transmitted signal has high-frequency pre-emphasis to help maintain picture definition) and passed to the NE592 video amplifer.

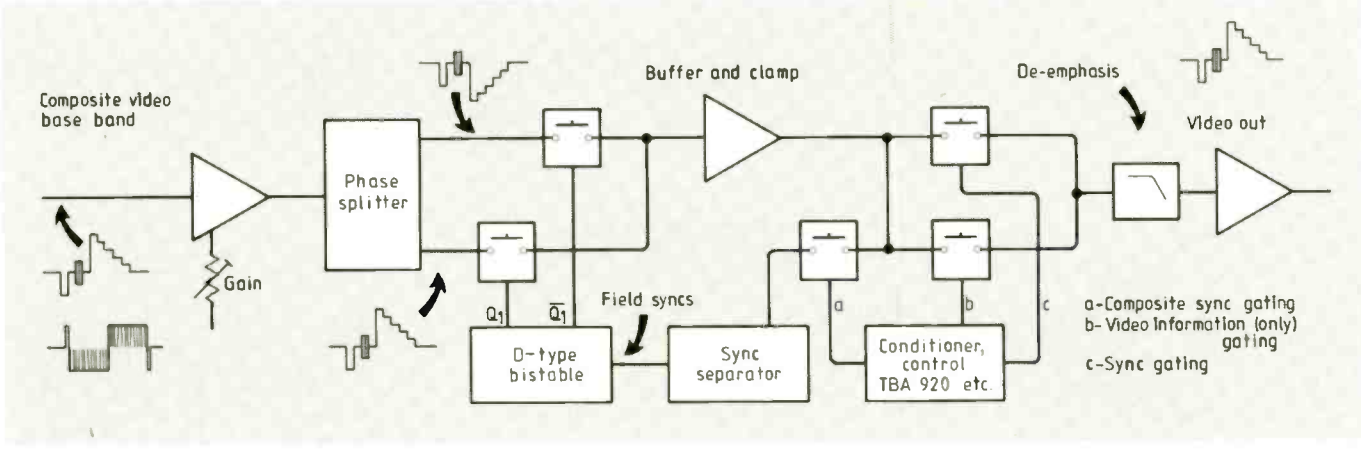
ADJUSTMENT

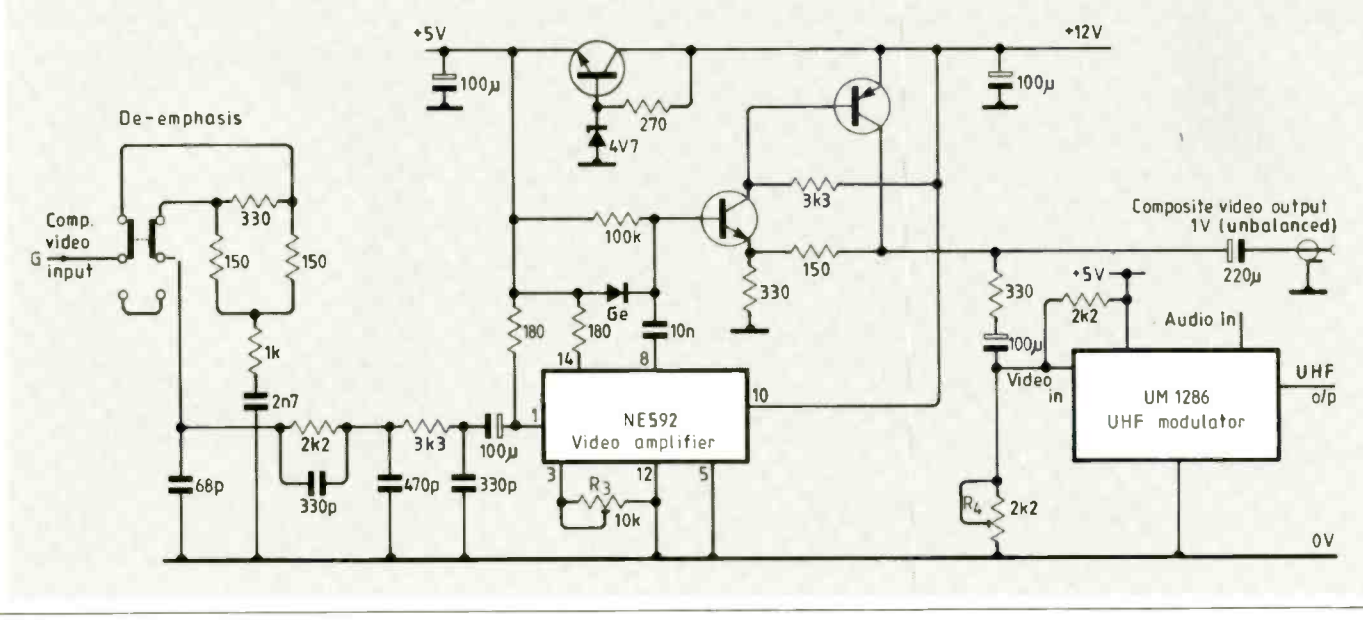
With the switch at position 1 (clear), load the video output of the decoder with a tv set, video recorder or 75 ohm resistor. Connect an oscilloscope at TP and adjust R_1 for a noise-free sync pulse. Adjust R_3 for approximately 1V pk-pk video output. If you are using the UHF modulator, then R_4 should be adjusted for best peak whites with no glowing or audio buzzing. It may be necessary to back off R_1.

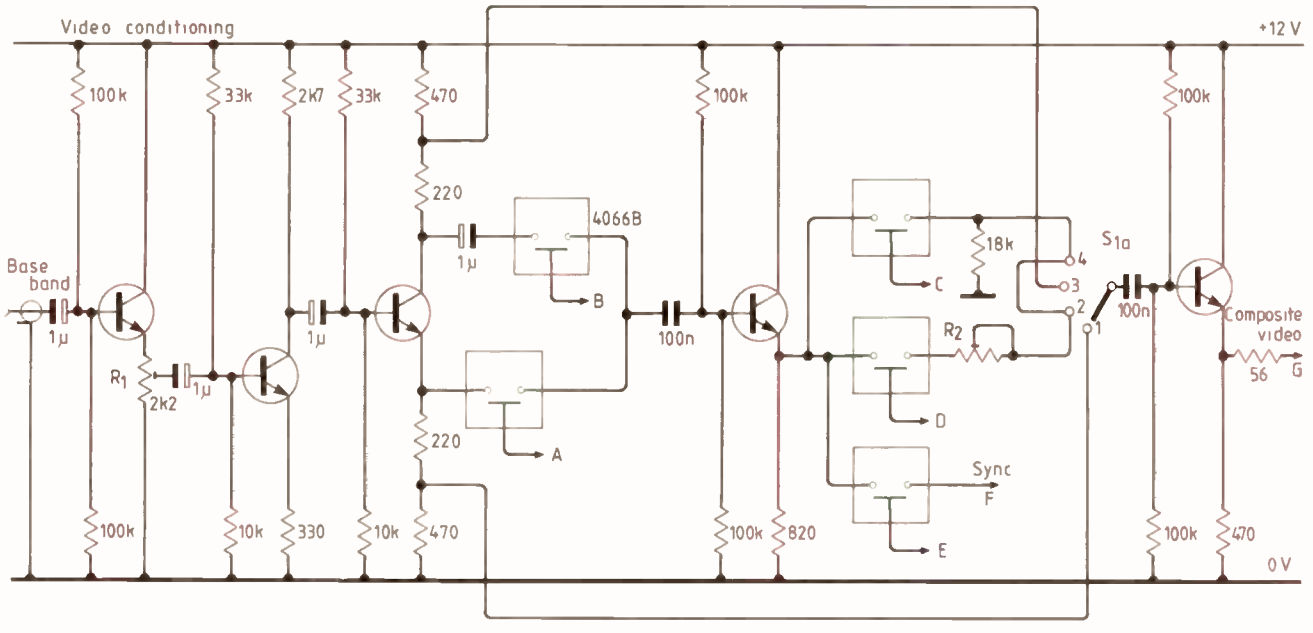
Now tune to ATN-Filmnet and switch to position 2 or 4. Whilst examining the video output on the oscilloscope, adjust R_5 (line phase) until the switching pulse is half-way along the back porch, whilst adjusting R_6 (line hold) to prevent horizontal picture tearing. Next adjust R_7 until the picture stops bouncing or rolling vertically. For best effect it may be necessary to return once more to R_5 and R_6. Finally adjust R_2 for correct black level on the oscilloscope.

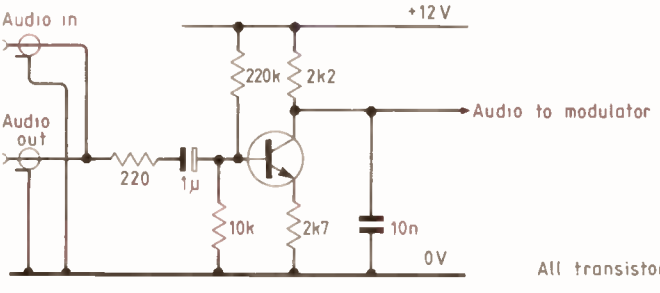
To test adjustment of R_6, tune slightly off channel on the receiver and rapidly back: the picture should synchronise in less than half a second.

Position 3 on the switch is provided for encryption where the video is inverted. This type of signal is now rare, but with this position Premiere and Channel 10 can be very nearly decoded save for a disturbing pattern of broad stripes of varying brightness rolling down the screen. These stripes are due to the AC component (100kHz for Premiere) of the composite scrambled information. It should be possible to insert a notch filter or some phase cancelling network to remove it.



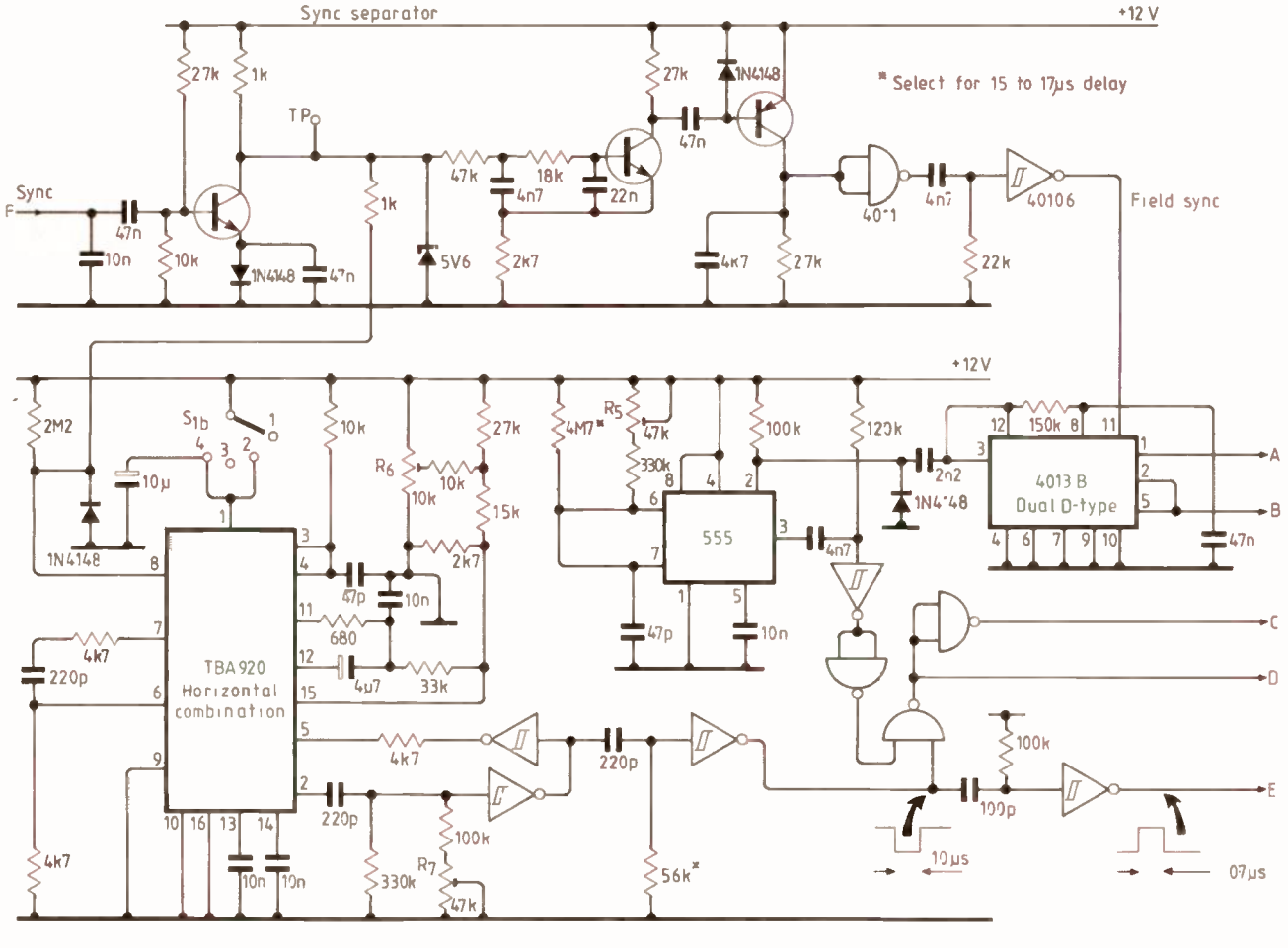






Switch position
1 Normal
2 Filmnet
3 Première (Ch 10 etc.)
4 Filmnet

All transistors BC183 or equivalent



Eurocypher

With the spread of satellite broadcasting will come the routine use of conditional access techniques. British Satellite Broadcasting has adopted the Eurocypher system, based on General Instrument's Videocipher II.

DAVID EGLISE

Conditional access allows the introduction of subscription and pay-per-view (PPV) television services, which will augment the income from traditional advertising revenues. For the broadcaster, conditional access also simplifies the purchase of programme rights, since the regions and countries in which the programme will be available can be clearly defined. It is widely believed that successful, high-quality satellite broadcasting can only be achieved with the support of a secure and flexible conditional access system.

It was against this background that Eurocypher was devised. The future of satellite broadcasting lies with the D-MAC transmission format, which has been developed to match the characteristic of the FM satellite broadcast channel. D-MAC is ideally suited to conditional access since the audio and video components are in a form that can be readily processed (or 'scrambled') to make them unintelligible to a normal receiver. Plenty of spare data capacity exists within the D-MAC signal to deliver the authorising signals that allow specific receivers to descramble the signals.

CONDITIONAL ACCESS

A conditional access system can be considered as two separate processes. The first step is to scramble the broadcast signal. Here Eurocypher uses the standard D-MAC techniques of modulo-2 addition of a scrambling sequence for sound and data components, and cut-and-rotate scrambling for the video component. Both of these methods use scrambling sequences produced by pseudo-random binary sequence (PRBS) generators, which are initialised every few seconds with a new control word. The control word determines that start point in the pseudo-random sequence and its frequent changing ensures that the television signal is highly protected against unauthorised use.

The second process is to deliver the control words to specific receivers. This is accomplished by the conditional access system.

The control word is sent in a stream of repeated messages, known as entitlement checking messages, or ECMs. These are provided in a special data service in the digital sound/data multiplex of the D-MAC signal. To derive the control words, the receiver must be in possession of a hierarchy of keys which culminates in a key known as the *session key*. This changes every few weeks, which allows time for the next session key to be delivered to authorised receivers. To do this the session key is acquired from a key that is unique to each individual receiver. The message so formed is included in another stream of messages, known as entitlement management messages, or EMMs. Each receiver is periodically sent an EMM containing the session key encoded with its own *unique key*. Unique keys are programmed into the receiver during manufacture and a secret list of receiver identities and their unique keys is kept by the authorising authority.

Overlaid upon this basic system structure are additional features which protect the security of the system and enhance its flexibility. Information about the programme being transmitted is included within the accompanying ECM. This includes information such as the programme name and how long it has left to run, together with data relating to conditional access, describing the price of the programme (for PPV) or maturity level of the programme content.

ADDITIONAL SERVICES

A D-MAC signal can carry a number of other services in addition to television. Eurocypher can provide independent scrambling for these with parallel ECM streams, carrying the conditional access data for their associated service.

EMMs also contain more than just conditional access information. Each EMM is intended for a specific receiver and contains information relevant to the viewer associated with that receiver. This would include details of the various services that the viewer is entitled to, the geographical location of the viewer's home, and possibly an electronic credit signal for PPV systems.

PAY-PER-VIEW

Eurocypher allows two forms of PPV operation. The simpler version requires the viewer to decide in advance whether to pay for a particular programme item. This would typically be an international sporting event such as a football or boxing match. Orders for the event would be taken by telephone and post in the days before the event is transmitted, and the individual receivers authorised via an EMM. Although this method is practicable for small audiences, a rush of last-minute purchases would quickly overwhelm the booking system.

A more sophisticated version is impulse pay-view, or IPPV. Here EMMs are used to transfer credit to an electronic money box in the Eurocypher receiver. ECMs for a PPV event then provide the purchase price of the programme. Details of the event, its purchase price, and how much is in the receiver's money box are shown on the television screen. If the viewer wants to buy the programme, he or she enters a personal identification number (PIN) via the remote control unit. This can be done on impulse at the start of the event or shortly after. The cost is deducted from the credit total. When credit eventually runs out the viewer must contact the authorising agency and arrange for a further EMM to be sent.

A complication of IPPV is the need for statistics on the number of people purchasing it. Eurocypher accommodates this by providing a report-back facility. Periodically it uses the telephone network to download records of what has been purchased to a computer system at a PPV centre.

GEOGRAPHICAL BLACKOUTS

It is possible to deny access to a programme item according to the geographical location of the receiver. This can be used to advantage when purchasing programme rights, since the owner of the rights knows that the event will be seen only in specific countries. A further refinement is to "black-out" an area surrounding the site of a sporting event, so that the promoter can sell the rights for television coverage without fear of harming the attendance figures.

Yet another feature is the ability to black-out specific items, such as an advertisement, from a region where it may be considered unacceptable. Throughout Europe, a host of different rules apply to products such as tobacco, alcohol, contraceptives, and advertisements directed towards children.

The requirements of Europe form a strong thread running through the Eurocypher system. Provision is made for displaying text messages in different languages, depending on which country the receiver is in. Prices of PPV events can be assigned the appropriate currency symbols (£, Dm, Fr etc.) whilst displayed times will take account of time-zone differences and daylight-saving adjustments. Even the parental control function can have the programme rating displayed in a manner consistent with the cinema rating system for that country (e.g. X, PG, U for the United Kingdom).

EMMs sent to particular viewers have the capacity to control authorisation for up to 512 different programme packages. Such a package could include programmes on one particular channel or on several channels having a common ownership.

Further reading

IBA Technical Review 24, The D-MAC/packet System for Satellite and Cable. Independent Broadcasting Authority, November 1988.

David Eglise is Director of Technical Services, British Satellite Broadcasting.

High-resolution frequency counter

High-stability clock, display protection and PC interface for the instrument described in the January 1988 issue

STEPHEN THEOBALD

The clock oscillator described in the January issue was a standard design built around a single 74HC-type inverter. This circuit is reliable and simple, but its performance is far from ideal. HC type c-mos gates have input currents and capacitances which are both heavily voltage dependent when they are used as amplifiers with DC feedback, and the output from such an oscillator is easily seen to be a far cry from a pure sinewave. These factors, together with temperature-dependent propagation delay and the temperature coefficient of the external capacitors, make it seem unlikely that this simple oscillator will show good frequency stability. In an attempt to confirm this supposition, a few tests were carried out on similar oscillators built using c-mos gates and small ceramic capacitors. One oscillator showed a remarkably small temperature dependence of less than −2 Hz/°C in the region 10–40°C, while another was poorer at about −7 Hz/°C. A commercial oven-stabilized oscillator was used to drive the frequency counter while these tests were performed.

These figures are probably not particularly accurate, since the equipment used for temperature cycling was rather primitive (ice-cubes and large transistors mounted on a heatsink inside an insulated box) and the time-consuming nature of these experiments prevented further investigation. The results do, however, indicate that if the full seven-figure accuracy of the counter is to be realised, then some better clock source is required, bearing in mind too that the temperature rise inside the case of the counter can easily exceed 20°C even with good ventilation. It is at any rate wise to position the oscillator components as far from the power supply as possible, since this is the main heat source within the instrument.

When the clock-inhibit switch, S_3, is closed, the internal oscillator is disabled and the instrument can then be operated with an external clock source when greater precision is needed. An ovened crystal oscillator providing tight temperature control and using flow-temperature-coefficient capacitors should be capable of maintaining an accuracy of about 1 part in 10^9 or better. Suitable units can be built, which is difficult, or bought, which is expensive. They are also unfortunately rather bulky and consume a fair amount of power because the oscillator runs at an elevated temperature; 70° to 80°C seems to be typical. Long-term ageing effects will also mean that periodic, though infrequent, calibration will be necessary.

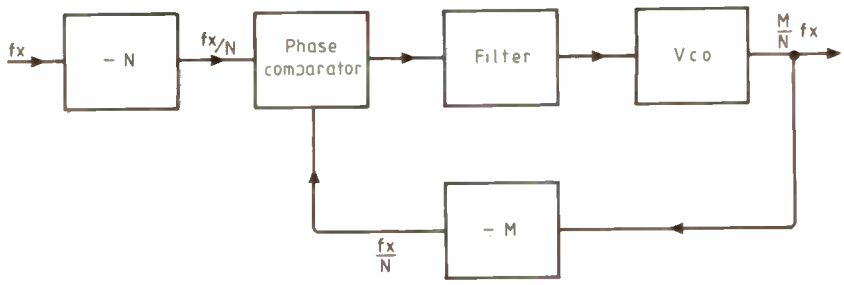


Fig.1. Phase-locked-loop clock source to provide 5MHz from unhelpful carrier frequencies.

Where the ultimate in accuracy is required, a clock source derived from, and phase-locked to one of the highly stable LF transmitters such as Rugby, Droitwich and Kalundborg (Denmark), provides the very best solution. These stations transmit frequencies accurate to better than 1 part in 10^{10}, which is at least two orders of magnitude more precise than we in fact need. Designs for suitable receivers have appeared in the pages of *Wireless World* and other electronic journals from time to time,[1,2] and these can supply the reference input to a phase-locked frequency multiplier. Integrated circuit manufacturers have taken most of the problems out of the design of phase-locked loops these days, and data sheets usually contain helpful advice, or even complete design examples.[3]

The transmitters mentioned above have slightly unfortunate carrier frequencies which cannot simply be multiplied up to exactly 5 MHz. This means that the carrier must first be divided down to some convenient frequency, say 5 or 10 kHz, before being multiplied. A block diagram of such a system is shown in **Fig. 1**, and it is clear that large division ratios may be required in the feedback path.

The microprocessor-based frequency counter can, however, simplify the design of the PLL stages owing to its in-built computing capability. Although designed to work with a 5 MHz clock, the instrument can be arranged to work with any clock frequency in the range of 4 to 6 MHz, provided that a few minor changes are made in the contents of the rom. When these changes are made, the input divider in Fig. 1 can be omitted, and only relatively small divisors appear in the feedback path. The changes necessary are the writing of a four-byte floating-point number and its reciprocal at certain addresses, and the resetting of a flag. The microprocessor uses the numbers to adjust the results obtained on the assumption of a 5 MHz clock if the flag is reset. The process is perhaps best explained by the use of an example. Consider that we wish to use the Rugby transmitter broadcasting on 60 kHz.

We first choose a convenient multiplier which will bring this frequency up to somewhere in the vicinity of 5 MHz. The figure of 80 is decided upon, which will increase the LF signal to 4.8 MHz.

$$X = 5/4.8 = 1.0416667 \text{ and } Y = 4.8/5 = 0.96$$

These are converted into binary form, giving

$$X = 0.1000\,0101\,0101\,0101\,0101\,0101 \times 2^1$$

$$Y = 0.1111\,1010\,1110\,0001\,0100\,1000 \times 2^0$$

Note at this point that all working must be done to an accuracy of 8 decimal digits and 25 bits, the 25th bit being rounded up or down as necessary, and that X and Y both have a fractional part, F, such that $0.5 \leq F < 1$. X has been post-multiplied by 2 in the example to achieve this.

These are now converted into hexadecimal, four-byte values, the fourth byte being the power to which 2 has been raised. Thus

X′ = 85 55 55 01 and Y′ = FA E1 48 00

These bytes are now written as a string in reverse order, 00 48 E1 FA 01 55 55 85, and stored in the rom at addresses OFF0 to OFF7, in the given order. Doing this will also automatically reset the necessary flag. The bytes at these addresses are all FF originally.

Anyone considering using this technique should note the following points:

- The frequency decided upon must not lie below 2.5 MHz or above 6 MHz. Frequencies under 5 MHz will slow the instrument down, and 4 MHz is probably a usable lower limit.
- The 5 MHz crystal in the internal oscillator should be replaced by one having the same frequency as the external source.
- Lowering the clock frequency will also lower the maximum PRR which may be applied to the input in the event mode without pulses being missed.
- The counter will perform normally on all functions except the CLOCK function. This one function is interrupt driven and demands a 5 MHz oscillator.

PROTECTING THE DISPLAY

The multiplexed display of the frequency counter is run at a much higher current than the devices can stand during static operation. Each segment is driven with a current in excess of 30mA, but this is quite safe provided that each digit is only turned on for one eighth of the time. However, if the multiplexing action should cease for any appreciable length of time, there is a great danger that some of the segments may be damaged, resulting in reduced brilliance from that part of the display henceforth. If the worst comes to the worst, one of the digits may even burn out completely.

The instrument has been designed to ensure that this cannot happen during normal operation, but there is the ever-present risk of disturbances on the mains upsetting things. Noise spikes, for example, can quite easily propagate through the power supply and either cause the microprocessor to malfunction for a short time or cause incorrect data to appear on the busses. If the microprocessor, by this or any other means, gets out of step with its program, it is highly probable that the scanning of the display will stop with one of the digits turned on. The instrument has not shown itself to be unduly prone to such problems, but some means of protecting the display is obviously desirable.

A simple LC filter on the mains input will be able to reduce the effect of spikes and of course can be recommended, but this does not offer complete protection, nor will it guard against short-term drop-outs which can occur from time to time.

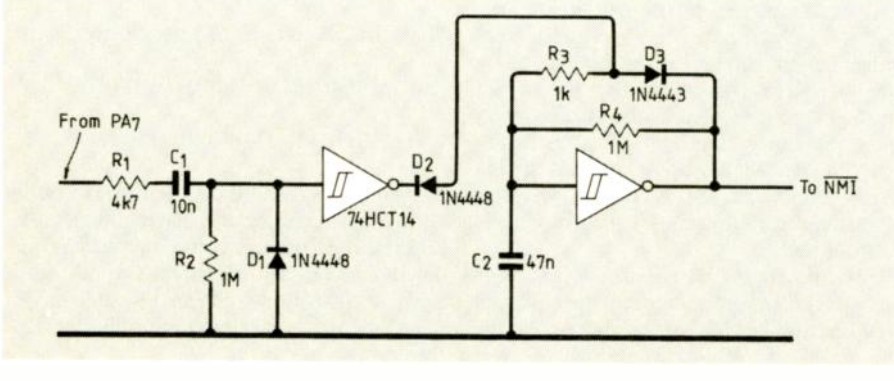
A better solution, one which guarantees full protection against all malfunctions caused by external influences, is a watch-dog circuit. This is standard equipment in a great many microprocessor designs nowadays, and is simple to implement. It works by monitoring some recurrent behaviour of the system and resetting the system to some well-defined state if the expected behaviour fails to occur. In the case of the frequency counter, it is clear that we should monitor one of the anode drive circuits of the display, the PA7 output of IC_4 being particularly suitable. This output does not drive any digit, but is multiplexed along with the other seven output lines all the same. A rectangular wave with an 87% duty-cycle is available at this point.

Figure 2 shows a simple circuit that may be used to implement the watch-dog function. The PA7 output is capacitively coupled to the input of the first inverter so that only dynamic multiplexing can affect the inverter. Diode D_1 restores the DC level of the waveform. So long as multiplexing takes place, the output of the first inverter will also be a square wave with the same frequency as the input. Each time that the inverter's output goes low it will discharge C_2 via D_2, maintaining the second inverter's input at a low level and its output high. This point is connected to the NMI input of the Z80B, which is active-low, so that in this condition the processor is not interrupted.

However, if the multiplexing should fail at any time, resulting in a static output from PA7, the input of the first inverter rapidly falls low, its output goes high, and D_2 disconnects it from the following circuitry. The second inverter is now able to function as a low-frequency oscillator, providing short negative pulses at its output which interrupt the microprocessor. The microprocessor will always respond to these interrupts, jumping to the routine starting at address 0066. This routine first of all blanks the display completely and then pulses the PA7 output rapidly up and down for about 200 ms. This then puts an end to the interrupting signals and the routine finishes by restarting the microprocessor at address 0000, which is the normal starting point of the program. Even prolonged and very irregular disturbances of the system will not prevent the instrument from eventually starting up normally again because the watch-dog will go on oscillating and interrupting the microprocessor until multiplexing is re-established. The chances of an AC signal appearing on the PA7 line if the program is not running correctly are very remote, perhaps almost impossible.

The inverters for the circuit could be the two spare ones in IC_{12}. This circuit was specified as a 74LS14 in the January article, but may be replaced by a 74HCT14. The NMI input was also shown connected to the +5V rail, but must of course be disconnected from this if the watch-dog circuit is to be incorporated in the instrument.

Fig.2. Watchdog circuit avoids damage to the display in case of multiplex failure.



INTERFACING THE COUNTER TO A COMPUTER

It is quite some time ago now that design work first started on the frequency counter, and no thought was then given to equipping the instrument with a computer interface. It should be possible to do this, however, providing not only for the transmission of measurements from the counter to a computer or data-logger, but also allowing the counter to be completely remote-controlled. Note that the interface design which is presented here has not been built, but it is straightforward and should work without difficulty. The design will not prove suitable for all computers, but enough information is given to allow the reader to adapt it to his/her needs.

The well-known 8255 24-bit I/O port has been chosen for the immediate interface to the computer. This device can operate in three main modes, mode 0 being chosen for this application. In this mode ports A and B operate as two independent 8-bit input or output ports, while port C operates as two 4-bit ports. In the diagram, **Fig. 3**, port A is output while B and C are inputs. It is not intended to deal with the detailed working and control of the 8255 here, and would-be users are recommended to refer to Intel's data sheet[4].

Let us consider port A first; this controls the functioning of the frequency counter. Bits A6 and A7 are used to switch the two relays governing gain and coupling in the preamplifier. Bits A4 and A3, clocked through the latch IC_2, replace switch $S2_a$/$S2_b$ in the diagram in the January issue, while the lowest three bits of the port and the associated circuits IC_3 and IC_4, an 8-input multiplexer and a 3-to-8 line decoder respectively, replace $S1_a$/$S1_b$. All of these switches should be removed from the counter entirely. The accompanying table in Fig. 3 shows which control word the computer should write to port A to obtain any particular function.

Synchronization of data transfers between two asynchronous systems is nearly always a difficult matter, as witnessed here by the presence of IC_5 and the use of bit 6 of port A. When a new function is to be selected in the

frequency counter, the appropriate control word should be sent to bits A0 – A4 with A5 low. It should then be sent again about 1 ms later with A5 high, and once again 1 ms later with A5 low. The clock signal for IC_5, a dual D-type flip-flop, is the same signal used to clock the display output ports. This clock occurs about every 820 microseconds. The net effect of the above procedure and the flip-flop delay line is to ensure that data is stable on A0-A4 before IC_2 is clocked from the pulse out of A5, at a time when the display is being refreshed; i.e. when the new data is not being examined by the counter. This allows the counter to change cleanly from one state to another without passing through any undesired states. If this procedure is not followed, it would be possible to overwrite the stored frequency in the counter's memory by accident.

If the counter is switched from one function to another, it reacts rapidly in most cases to perform the new function. This is not always the case however. In particular, moving horizontally in the upper four rows of the table of Fig. 3, it may take up to a second before the counter reacts, plus another second before a reliable reading becomes available. Moving vertically between rows 101 and 100 the reaction is very fast, and a valid reading is available within 10 ms. The same applies for vertical movement between rows 011 and 010, and for transitions in any direction in the lowest two rows.

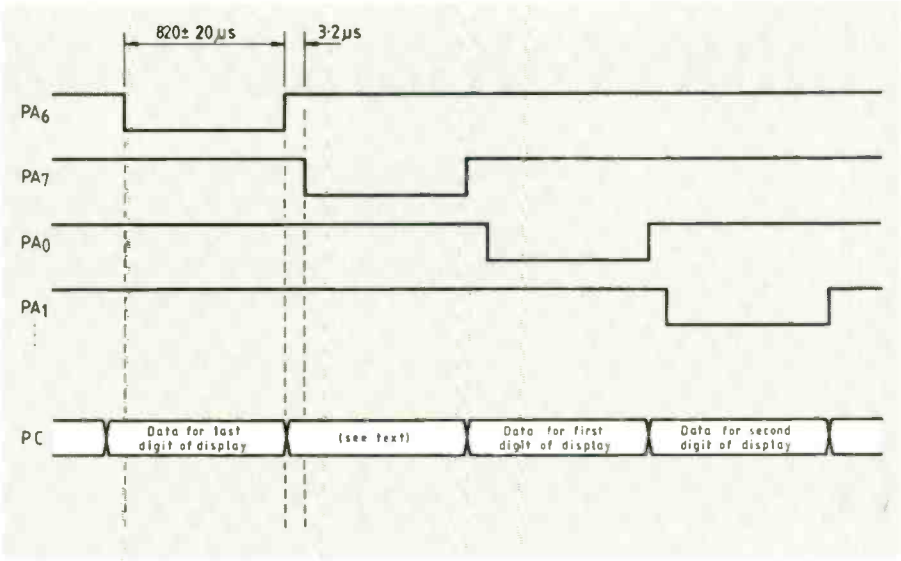


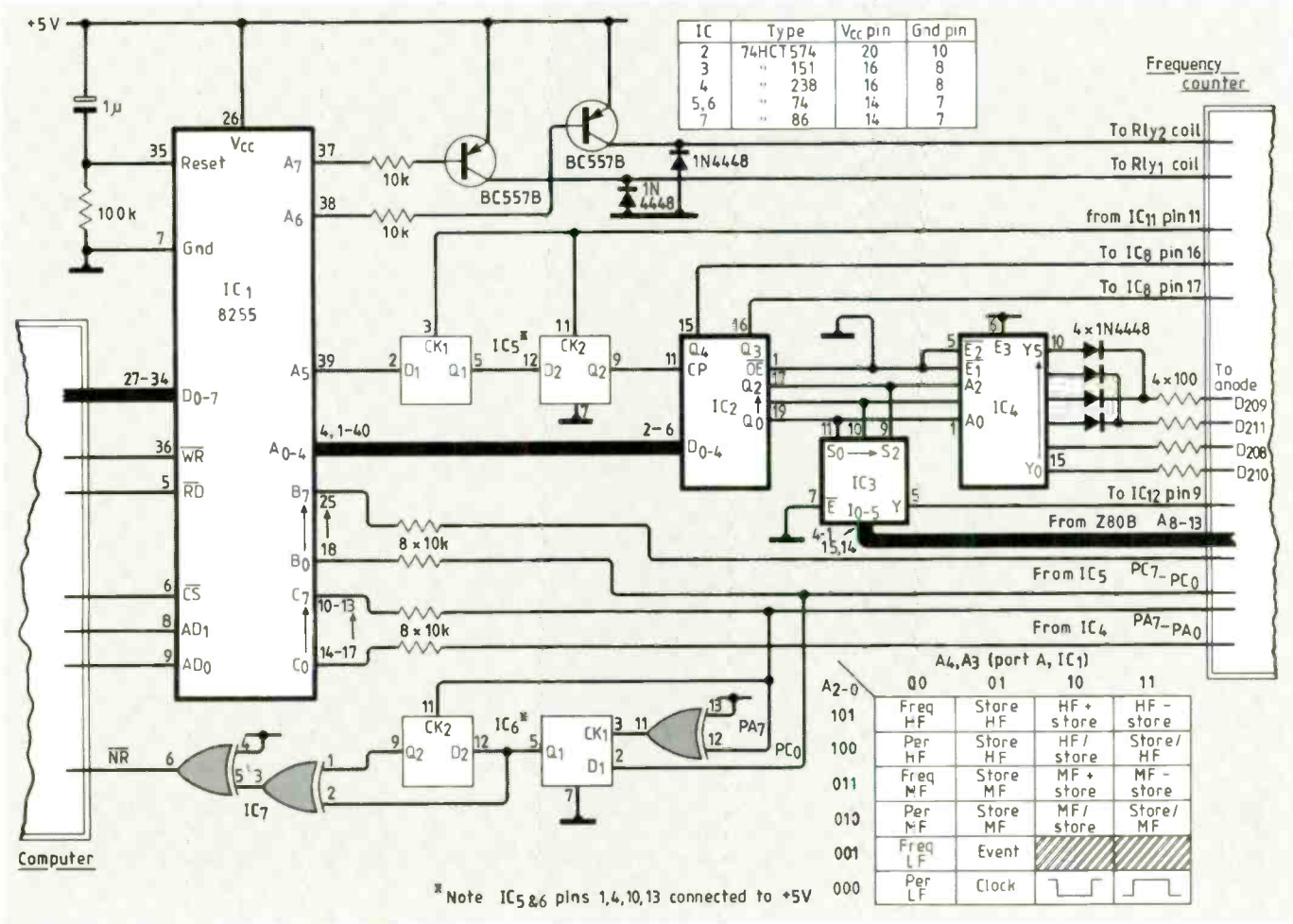
Fig.4. Timing of data on display output ports.

Ports B and C transmit the results from the display out onto the computer bus. Data received by the computer is obviously in the same format as that used by the display, and if the data must be mathematically manipulated, the computer will have to be programmed to convert the data to some more amenable form.

There are a couple of points worth noting in connection with the display. The first is illustrated in **Fig. 4**, which shows the timing of data on ports PA and PC in the counter. We see that the anode drives of the separate digits do not overlap, and that data is valid on PC 3.2 microseconds before the associated line of PA goes low. The second point concerns the data on PC. The lower nibble

continued on page 379

Fig.3. Interface between counter and computer.



IC	Type	Vcc pin	Gnd pin
2	74HCT574	20	10
3	" 151	16	8
4	" 238	16	8
5,6	" 74	14	7
7	" 86	14	7

A4,A3 (port A, IC1)

A2-0	00	01	10	11
101	Freq HF	Store HF	HF + store	HF - store
100	Per HF	Store HF	HF / store	Store / HF
011	Freq MF	Store MF	MF + store	MF - store
010	Per MF	Store MF	MF / store	Store / MF
001	Freq LF	Event		
000	Per LF	Clock		

Object-oriented programming

Structured languages promote modular programming, but the modules that result have their data held remotely. Rupert Baines describes the advantages and disadvantages of a programming 'environment' that allows only completely self-contained modules.

RUPERT BAINES

Of all the areas of high technology, that of software seems especially subject to sudden enthusiasms and fashions. Ideas seem to arrive from nowhere and become established as common knowledge almost immediately. Others fall from favour just as fast. Who had even heard of C five years ago, let alone used it? Yet today it is perhaps the single most popular language.

The idea attracting attention at the moment is that of object-oriented programming, or oops. Despite (or possibly because of) all the ballyhoo about oops, it is surrounded by confusion and misunderstanding. I hope that this article will describe the subject and clear some of the confusion.

So, just what are oops and why are they so controversial? What is all the fuss about and is any of it justified?

An oops is simply a programming language. The reason that oopss are important is that they work in a slightly different way from normal languages. By offering a subtly different set of tools to the programmer an oops provides a different way of solving problems. Enthusiasts claim that this new approach makes software clearer, shorter and more reliable while making the programmer more efficient.

Over the four decades that people have been using computers there have been many different ways of programming them, progressing from hard wiring and machine code to high-level and fourth-generation languages.

Despite apparent diversity in the many different languages that exist now, most of them conform to the same philosophy, i.e. they are organized in basically the same way.

Until twenty years ago, computers were real computers, filling large rooms with their air-conditioned extravagance. And the languages with them were cryptic monstrosities like Cobol or Fortran 66, which seem terribly restrictive nowadays. You are only allowed short variable names, the control structures are very limited and there is very little flexibility or modularity. There were few data types, and no way of defining more.

With these older languages the only control structure was GOTO so the programs were totally controlled by a network of jumps and re-jumps which would (perhaps) be documented and analysed using flow diagrams. It is possible to write clear, well structured programs in them – although they don't make it easy. But what did that

SON OF C

The C++ programming language is the work of Dr Bjarne Stroustrup at Bell Labs (where C was born). It started as a project to correct some of the perceived failings in C by providing various enhancements and expansions to the original language. However, development progressed until a whole new language evolved.

The compiler was first released outside the lab in 1984 and shortly afterwards Dr Stroustrup published his book The C++ Programming Language which is very much the definitive specification (thorough and comprehensive it is; clear and readable it isn't!).

The simplest way to describe C++ is as a superset of C; the old language is all there, complete with the cryptic commands and standard libraries that C programmers are used to. However a vast number of new facilities and functions have been added.

Since the standard language is still supported, any code written in C will run under the new environment (always assuming that it ran before). This means that investment in systems, software or programming skills can be transferred without waste.

A programmer could start by using only the conventional functions, gain familiarity with the system and gradually use the powerful object-oriented aspects of the language when they became relevant.

Since the 'learning curve' for pure languages like Smalltalk is notoriously gradual, this easy entry can be very attractive. The benefits of starting from the secure base of an already popular language and then building on that to offer the power and flexibility of an oops explain why, despite its youth, C++ is so successful.

The language supports a number of minor extensions to the original C as described by Kernighan and Ritchie. This isn't to devalue the extensions; they improve the language significantly. They include having genuine constants from within the language, function prototypes and more rigorous type checking (I can hear the gasps of horror). These may all seem familiar; having originated in C++ they've been adopted and used by many compiler writers including the committee which specified ANSI C.

There are also the object-oriented aspects of the language, allowing the programmer to define new classes and redefine existing ones. These can work happily with the rest of the system, allowing us to enhance our existing programs. To prove how useful objects can be, C++ includes some predefined classes, just waiting to be applied. The most useful of these to the novice C++ programmer will be the stream classes, which radically simplify i/o operations.

In conventional C the programming relates to the real world using five streams; stdin, stdout, stderr, stdaux and stdprn. These have now been simplified to only two classes; istream and ostream, which (obviously enough) deal with input and output respectively (for example stdout is part of the ostream class).

If an object is to be printed, all the programmer has to do is send the data to this stream using the '<<' operator. If the source code for this is examined all the usual 'putchar' output routines are found but the user needn't access them; the definition of the object chooses which routine is to be used.

At last a programmer has a general-purpose print function without needing to worry about a tortuous set of Printf() masks.

In the past all C++ systems have been written as code translators, which interpret the code and translate it into standard C to run on your existing compiler. This isn't the quickest way of doing things (although it does guarantee that your code is truly upwards compatible with the usual language).

A better way of doing things is to write a genuine C++ compiler, which has now been done by Zortech (as far as I know this is the only one available – if you know differently please tell me). It is a fast and powerful system, being the latest development of their deservedly popular C compiler, and apparently is selling very well.

There are several translators available at a range of prices. Rumour tells of an excellent shareware version (which would be an ideal way of testing the language to see if you liked it). Unfortunately I haven't been able to find any details of this mythical bargain. If you know of it I'm sure there are plenty of readers who'd appreciate the information.

The definitive book on the language is obviously Bjarne Stroustrup's The C++ Programming Language, but it is definitely not an easy read. It is only to be tackled if you know your C and take your time. There are other books which will be easier going: one I found particularly good was The Waite Group's C++ Programming by John Berry, published by Howard Sams, which is a good introduction to the language. These should be available from most of the bigger software distributors or any good computer bookshop.

Their C++ compiler costs £95 from Zortech on 01-316 7777. C++ translators can be obtained from any good software dealer – just have a look through their advertisements.

matter when the only programmers were a rare breed of specialists who could cope with it all?

As more and more people became involved with programming, the new philosophy of structured programming, which is now almost universally accepted, began to appear. The principle is to adopt a 'top down' approach to program writing. You start by considering the problem as a whole, with the aim of dividing it into separate parts. These sections are continually divided and subdivided until you reach a stage where each module performs a single discrete task.

As a result, the total program is divided into a tree structure with the initial problem at the top and the fundamental modules at the bottom. The program will be a series of procedures and function calls, with the emphasis on a well defined structure and logical layout.

Languages like Pascal, C and Modula-2 that follow this philosophy (procedural languages) are designed to put an emphasis on program flow and therefore support lots of control structures including Repeat-Until, Do-While, For-Next, Begin-End, If-Elself-Then-End-If, and Case-Esac. These structures, defining the skeleton on which the program is built up, determine how the algorithm is constructed.

Data is different from the structure and the two are carefully segregated; data is purely passive as it gets passed between the active modules. This style of procedural language dominates today's software scene.

It is here that object-oriented programming differs from the more conventional procedural style. An oops starts from a 'bottom up' principle with emphasis on the data structures within the program rather than the control structures of it.

During the design process, the language is extended by defining new data types and new operations that directly relate to the needs of the application. These objects are fundamental to any oops; as they are combined and built upon, the application develops.

The crucial point about objects is that they contain code as well as pure data within the one definition. There is no distinction between the data and the code which will manipulate that data – both are needed to make up that object.

Smalltalk was the first oops to be developed and it is still the best. The Smalltalk environment (it is far, far more than just a language) was developed at the Xerox Palo Alto Research Centre during the late 1970s and early 1980s. It is based on a 'What If' structure; ignoring conventional wisdom the Xerox team followed their own ideas to produce a totally innovative view of computers and how humans can relate to them.

Many of the ideas that were developed as part of Smalltalk fifteen years ago are now making their mark on the computing mainstream; examples including windows, mice and HyperText. Often the versions we see now are only pale shadows of the originals. All these ideas are firmly based on Smalltalk, which is still *the* object-oriented language. There are other object-oriented languages but it is Smalltalk that they emulate.

In a Smalltalk environment there are only objects. Everything is an object, from an integer to the compiler, and they are all treated the same way. Everything is consistent in its approach in that everything happens by one object sending a message to another, and that is the *only* way that things can happen.

There is no distinction between the applications program, the language itself and the operating system. They are all objects and can be treated in the same way. If you do not like anything in the system it is just as easy to modify the source code of the compiler as it is to change your own programs (it would be a good idea to keep back up copies though!). It is this consistent, open attitude that makes a Smalltalk system so flexible.

Of the other object-oriented languages around most are 'hybrids', being based on a conventional procedural language which has been extended to include some object-oriented features. They are, for example, Object Pascal, the intriguingly named trio of LOOPS, SCOOPS and FLAVOR (which are object-oriented versions of LISP) and finally

LET'S TALK SMALL...

Smalltalk is the oops that really matters. If you're interested in the subject then it is well worth getting hold of a copy and giving it a try – but be warned it can be addictive!

There are three dialects in common use. One is Xerox Smalltalk 80. More than just a language, this system really is a complete environment complete with incremental compiler, windows support, debuggers, source code browsers, application programs and a vast library of application code and predefined classes. This is a direct implementation of the original Xerox PARC research project, and is therefore the richest implementation available. It is also the largest and requires some serious computing power – packages are available for Xerox, Sun and Tektronix workstations, the Apple Mac II; there are also versions for PC compatibles but I wouldn't bother unless you have a 386 model.

A better dialect for PCs and compatibles is Smalltalk/V, written by DigiTalk. This excellent system is based on the Xerox environment and is reasonably compatible with it. However it is a stripped-down version and better suited to the limited power of 8086-based machines. It still needs at least 512K of ram and a hard disk, though.

Finally there is Little Smalltalk, developed as a teaching package by Dr Tim Budd at Arizona University. Like the Tiny Basics on microcomputers of yesteryear, Little Smalltalk is a highly cut-down version of the genuine language, lacking the powerful graphics and many of the more sophisticated features.

Little Smalltalk isn't a professional development language and was never intended to be one. However it is an excellent entry into Smalltalk, capturing the essence of the language brilliantly. It supports all the functions that you need and enough of the luxuries to make using it great fun!

The Little Smalltalk package places much more modest demands on hardware than a full implementation. It is available for most micros including the PC, the Archimedes and the Atari ST. Finally it is in the public domain so the price is right too – what more do you need?

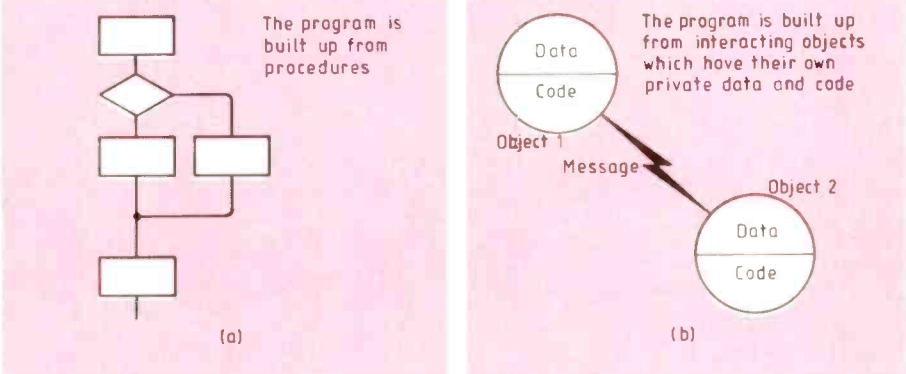
The genuine Xerox package is expensive. It is aimed at professional developers who can afford to pay good prices for good software. If you need to ask the price you cannot afford it.

Smalltalk/V for any PC with 512K of memory and a hard disk is available at the very reasonable price of £70. There is also an enhanced version called Smalltalk/V286 which needs a 286 processor and 2Mbyte of ram to give you surprisingly good results. This costs £135 and is worth every penny in my view. If you are serious about using Smalltalk then I doubt if you can do better than these packages. Digitalk deserves to dominate the Smalltalk market in the way that Borland has captured the Pascal one, and for the same reason. These are quality products at very reasonable prices.

Finally, Little Smalltalk is available very cheaply, thanks to Dr Budd's generosity in releasing it into the public domain. The cost you pay covers the price of the disks and the documentation. You can expect to pay £20-30 for an excellent introductory package – which is well worth the money if you are curious about the subject.

This package (and various others) are available from any of the good software distributors. There is a company who deal exclusively in the language – Smalltalk Express 01-200 0220. They run a bulletin board on the subject too; this is on 01-205 0512 and runs at 300/300, 1200/75 and 1200/1200 baud. There's a wide variety of applications, hints and support for all dialects of the language.

In conventional languages, like Pascal and C, a program is built up from procedures but in an object-oriented environment the program consists of interacting objects each with their own private data and code.



C++ which is an extension of everyone's favourite language (see panel).

Even ADA, the cumbersome monstrosity of a language designed by the US Department of Defense, is rumoured to support some object-oriented features (along with just about everything else!)

Logically enough, objects are the fundamental item in an object-oriented programming service. Each object is a complete sealed unit – it contains all the data it needs as well as the procedures to manipulate that data (its 'methods' in oops parlance). In a way an object is an extension of the Pascal record or the C structure, but not only do you specify the data structure but you can also define what operations are relevant and how they are to work.

Objects essentially have a public part and a private part; their public face relates to the outside world and to all the other objects by sending and receiving 'messages', which are then conveyed to the private body. This private body decides for itself whether or not it understands that message and, if it does, what to do with it.

When a message is received and recognised a method is triggered; this executes a section of code which processes the data and sends further messages on to other objects – computing happens. This is the *only* way that things can interact, by passing messages to each other – there is no way of directly accessing the inside of an object. Once an object has been defined you need never know how it is actually implemented, merely what messages to send to it.

This ability to keep objects totally self-contained and independent is one of the biggest attractions of object-oriented programming. For code to do anything at all a message has to be explicitly sent to an object that knows how to understand it and has an appropriate method ready. This means that it is virtually impossible to write a piece of code that has unexpected side effects – an extremely attractive feature.

Once a class of objects has been defined and tested the objects can be used in a variety of programs just by sending the appropriate messages. As time goes on and the programmer builds a stock of useful objects they can be built into any future projects without worries about interference or side effects.

"Unlike data types in normal languages, Smalltalk classes do not exist in isolation."

Developing re-usable code is one of the ways that oops makes programming more efficient. Most languages encourage you to re-invent the wheel; it is often easier to write a procedure from scratch than it is to modify an existing one to suit the rest of the program. An object doesn't need to be modified – it can be used directly. If messages are necessary these are easily added, without risk of altering the behaviour of any other objects.

Obviously, when you define a new type of object you can have more than one of them. Objects that represent the same type of thing and arise from the same definition are grouped together as members of a class. Every object in the environment is a member of a class (an 'instance' of that class).

Classes act as the template for all their instances (all the objects of that class that exist in the program) and they represent the definition of them. Accordingly a class stores all the information that is common to all – the directory of methods that are used when the object receives a message, the code associated with them and the details of data structures that each object will contain. Once a class has been defined new objects of that class, which can be created at will, can draw upon that same definition.

Unlike data types in normal languages, such as integers and characters, for example, Smalltalk classes do not exist in isolation. Instead they are arranged in a tree structure with parents and children. Objects which are instances of classes lower in the tree not only have their own definitions but they inherit those of their parents.

The tree diagram (p374) shows the built-in classes of a commercial Little Smalltalk system; instances of the class Float have methods and data as defined by their own class definition (Class Float) as well as those defined by all the parents – Class Number, Class Magnitude and Class Object.

When a message is received by an object the system looks for method in that object's class. If it finds one then that is executed. If it doesn't find a match the system will then move up one level and check the method directory of the parent mode. Again if the method is found, it will be executed.

This process repeats until either a match is found, in which case the message is run, or the system hits the top of the tree without finding any acceptable method for that message. In that case it generates an error, since the object has been sent a message that it cannot understand.

'Inheritance' of classes is the fundamental method of code re-use in all oops and it is amazingly powerful. Features can be defined higher up in the tree and then be used painlessly from the lower levels. This means that there is no occasion for any duplication of coding – objects can understand any message defined for their parent class.

Once you have a class which works reliably you can extend it by defining a new class as its descendant. This daughter class can use all of its parent's functions as well as its own. Because we know that the parent's code is reliable, opportunities for bugs are greatly reduced.

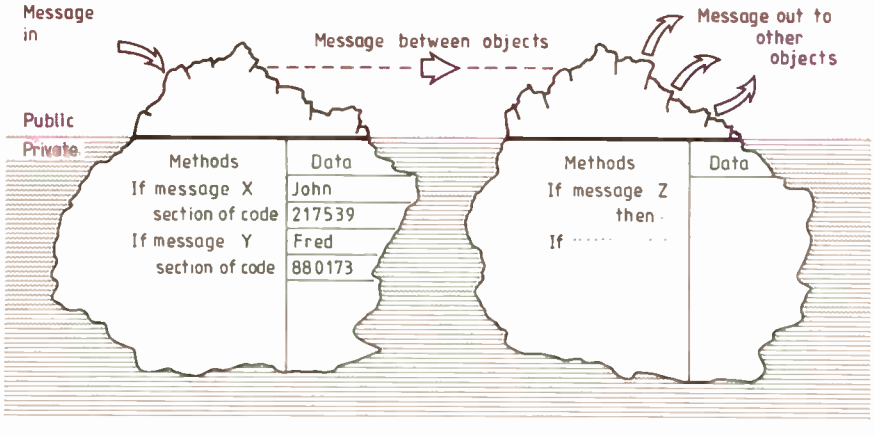
For example, suppose that you were to develop a program for architectural cad purposes. You might define a class of object called BUILDING, which will understand messages such as 'print plan' or 'show elevation'. This might have two sub-classes of HOMES and OFFICES; these would still accept the earlier messages but would have ones specific to their application (perhaps "Print number of bedrooms").

Sub-classes could have further sub-classes (e.g. bungalow, terraced house, semi-detached) with their own specific methods and messages depending on the needs of the system, but they would still simply use the already defined and tested routines from higher up the tree whenever necessary. Ultimately the classes could divide to give individual objects.

As a simple example of how an oops might be used in practice, imagine writing a program for increasing desk-top productivity. Part of this program is an address book, which can be represented by a single object. This will understand messages like 'Find Fred Bloggs' or 'Include Joan Smith'. Of course Fred and Joan will be objects in their own right elsewhere in the program.

Other objects might be a modem or a word

Objects are like icebergs in that most of their bulk is below the surface. The rest of the program can only see the 'public' face of the object; the private section is set up by the class definition.



processor that will use the address book by sending these messages, and getting other ones back. Because of the information-hiding aspect of objects the programmer who wants to use that address book need never know how the data inside it is organised – it might be a list or complex B-tree, or it may be plain ASCII or some compressed format – it doesn't matter. All the programmer has to do is send the appropriate message and the methods within the object will do the rest.

If the people stored within the address book fall into different groups then it would be a simple matter to set up different sub-classes to handle them. A business address file could understand a request like 'get Fred's fax number' for example.

As another example of how oops can help programming, imagine writing a program for manipulating complex numbers. In a conventional language you would have to decide how numbers would be stored – in a rectangular form as a+jb or in polar form as r,θ.

Whichever method you chose would be followed throughout the program consistently, with routines needed to handle conversions explicitly. Even worse, you would have to define a whole suite of procedures to handle the operations on these numbers since you cannot say

```
complex x,y,z;
z = x + y;
```

because the '+' operator is not defined for the type complex, and there is no way to redefine it. Instead we are forced to use expressions like

```
complex x,y,z;
complex  add (z,x,y);
```

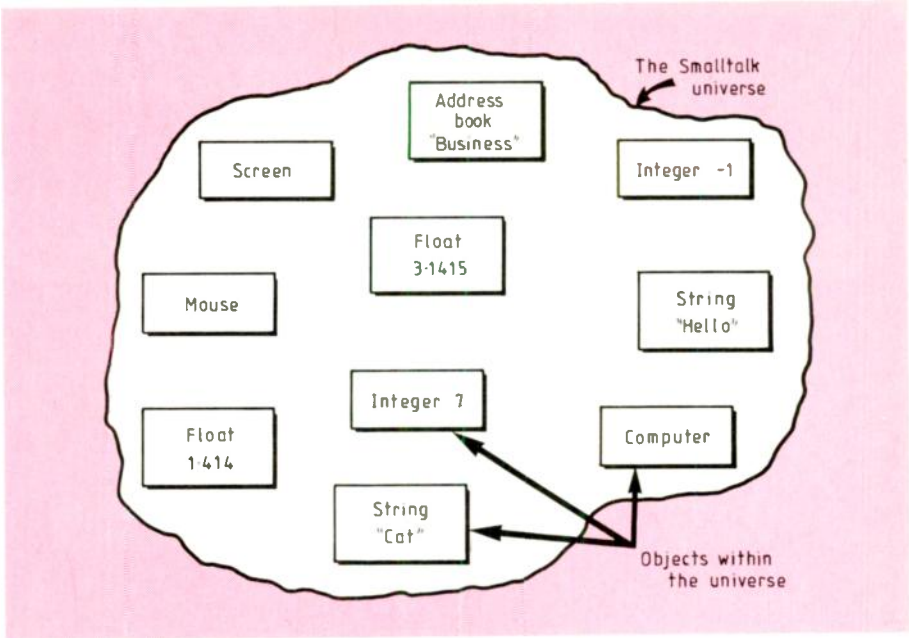
which is clumsier and less clear.

In contrast, an oops would allow us to define the object to represent a complex number in any way you choose, so that it can understand the conventional + symbol and react appropriately. The methods and internal data of the object would know which representation had been used (polar or rectangular) but it is irrelevant to the user who can send four messages to access a,b,r or θ at whim, allowing easy use of the information in either form. The conversions are done automatically and transparently by the object itself without the user ever knowing.

The object-oriented approach not only makes the code clearer (which of the code sections above would you find easier to understand?) but it makes it more versatile too by eliminating the need for conversion routines.

As a final thought, this idea of information hiding and message passing means program objects behave in a way that is akin to real world objects. When we use something physical we send it a signal and then expect it to handle the precise implementation.

For instance when you change the volume of a radio you neither know nor care what amplifier configuration it has or what is the value of the variable resistor. Most people are happy to leave the radio as a box that accepts messages at one end, converts them in the middle, and sends them out at the other end.



Smalltalk philosophy is very consistent, with everything in its universe being treated as an object.

The benefits of oops are that programs can be built up easily from independent, self contained objects. These can be sealed off from each other, only communicating through predefined messages and interacting in a known way. This makes bugs far less likely (and easier to trace if they do occur).

Once objects have been defined and tested it is trivially easy to re-use them for any other applications as building blocks – saving time and effort.

The concept of inheritance means that defining the classes that objects belong to can be a painless task too, since you can draw upon earlier definitions and make use of previous work. If there is a problem then it can only be in the newly defined item, since we know that the existing objects are error-free and there is no way that the two can interact except by deliberate passing of a message.

The way that objects reflect the real world makes designing an application simpler and easier to understand.

It is inevitable that any topic as new and as controversial as object-oriented programming has been attacked as well as praised. Many of these criticisms are unfair or unsubstantiated. Many more are fair as far they go, but tend to be criticising one particular implementation, rather than the idea as a whole.

"... imagine writing a program for increasing desk-top productivity."

It is undeniable that learning to use an oops can be hard work; many of the concepts are strange or unfamiliar and things are done in differently in relation to a conventional language.

It takes time to grasp the intentions behind the system and *why* things are done in a particular way. Compared with those of conventional languages, the concept of oops is so different that newcomers to programming often have an easier time with object-oriented systems than experienced software writers.

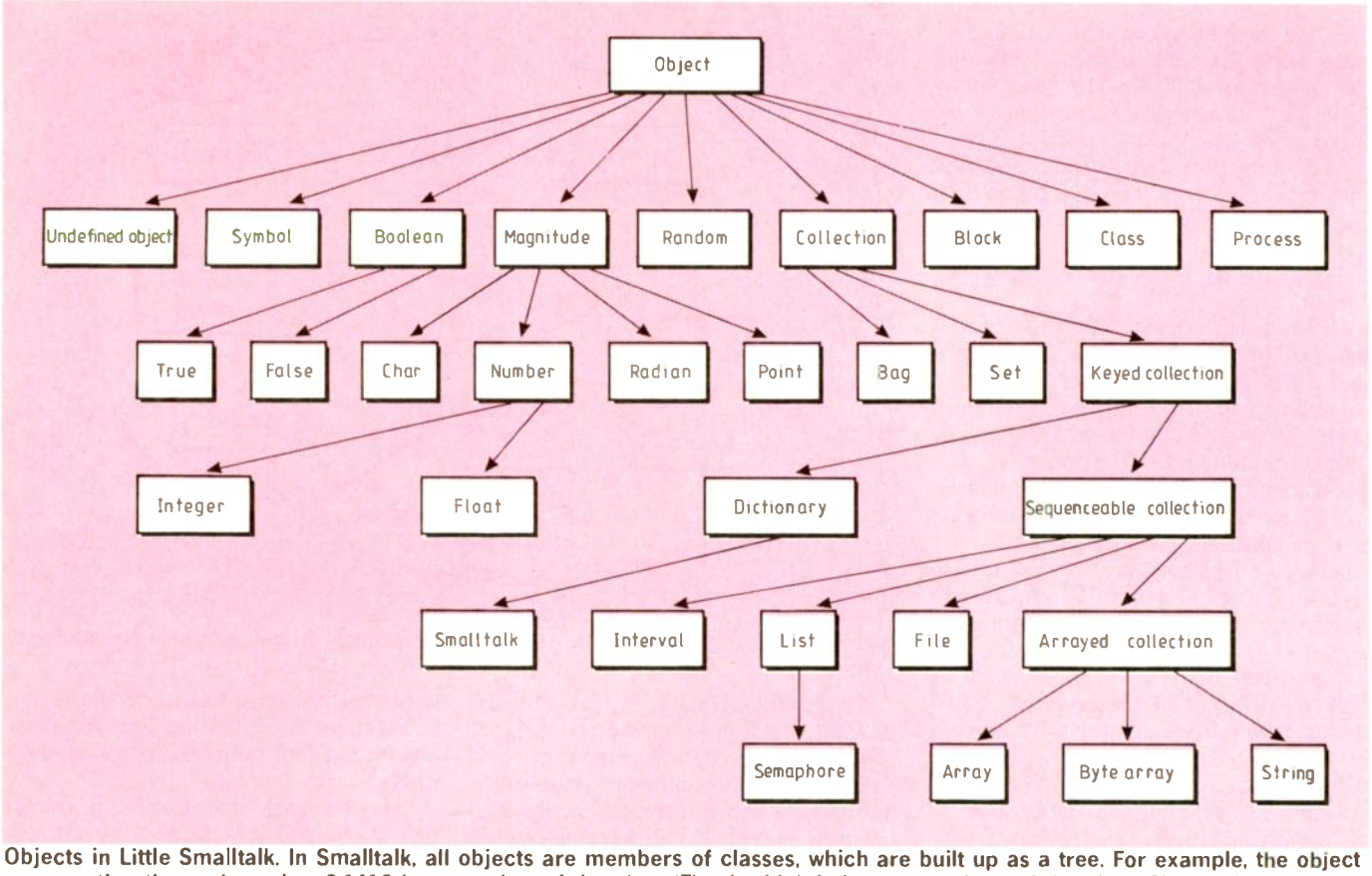
One way to shorten the learning curve would be to start with a hybrid language like OBJECT PASCAL or C++ (see panel). Initially, you could write all your programs only using the mainstream language in a conventional procedural style. Then you could gradually start to use the powerful object-oriented facilities as part of the main program.

In theory, as you gain familiarity with the ideas and appreciate the benefits, you will gradually end up writing exclusively in an object-oriented style. Once familiar with the concepts of object-oriented programming it would be a comparatively easy matter to transfer to another system like a full Smalltalk implementation.

Some people complain that they feel constrained and isolated from the machine when using an oops. Hackers and some old style programmers feel unhappy and alienated if they cannot fiddle with absolutely everything and anything within the system.

Since one of the key themes of the philosophy is that of containment it is hardly surprising that direct access to the raw innards of your machine is definitely not encouraged. For the majority of applications this won't matter, since the programmer will only be working on high-level functions.

Things that are very machine-specific or very time-critical – arcade games and real



Objects in Little Smalltalk. In Smalltalk, all objects are members of classes, which are built up as a tree. For example, the object representing the real number 3.1416 is a member of the class 'Float', which is in turn a subset of the class 'Number'. Ultimately, everything belongs to the class of 'Object.'

time control for example – are probably not suited to being written within the oops environment but would be better coded in a low-level language. Any application that can be written in a conventional high-level language could be coded using an object based language – and would probably be better written for it!

Finally if you ever did need direct access to the internal system then you can always extend the object definitions to allow it!

Similarly it is claimed that programs written in an oops will be larger and slower than those written in a conventional language. The size penalty arises because of the need for extra libraries and extra code to cope with the newly-defined data structures and operators; these may mean that the program is perhaps 10 or 20% larger than it would be if coded in another language. This won't matter for any real applications; most computers nowadays have hard discs, and programs typically are split into several sections, which are called as and when necessary so the total size of that program is essentially irrelevant.

The relative speed issue is harder to settle though, because of the different attitude of an oops. For example, object-oriented programs tend to do badly in benchmarks, but this is more a reflection on the test procedure than the relative speeds of the compilers.

Typically the benchmarks for testing a compiler are some fairly trivial procedures, for example counting to 1000, finding the first 100 prime numbers or sorting a few integers. These are of course well suited to conventional, procedural languages with their simple data types, but they are hardly fair tests for an object-oriented language.

The only realistic (worthwhile) test is to ask how well they compare in real applications that people actually want to use, and inevitably the answer is not clear-cut. The language used is of far less importance than the quality of the compiler and the skill of the programmer.

Quality of the implementation of the compiler makes a huge difference – the excellent Digitalk compiler for Smalltalk will outpace anything but the very fastest C compilers.

"One way to shorten the learning curve is to start with a hybrid language. . ."

". . .defining the classes that objects belong to can be a painless task too."

SHANNON, CODING AND SPREAD SPECTRUM

In this third article, the author examines error-correction coding techniques, concentrating on hard decision decoding

L. C. WALTERS

In the first article of this series (January), I showed that it is always possible in theory to effect, for a given communication performance, a linear exchange of bandwidth for operating signal-to-noise ratio. I also indicated that for input signal-to-noise ratios above some threshold level, r_T say, one could do rather better than this and in fact achieve a logarithmic exchange ($r_T = \frac{1}{4}$ or −6dB was suggested as a practical criterion).

The second article (March) was primarily concerned with means of achieving the linear exchange (applicable in principle for *any* s:n ratio), with especial consideration of a simple form of direct sequence spread-spectrum system.

This article considers basic ideas underlying error correction schemes; that is, means of approaching a logarithmic exchange.

Both the linear and logarithmic exchanges (when not used for bandwidth *compression*), involve use of redundancy (see March article); but unlike the spread-spectrum case, the "redundant" information in error-correction schemes is essentially related to the true information. Coding gain G_c was defined (equations 7 and 8) as the *additional* gain theoretically attainable (by use of suitable coding) over and above the linear "gain" due to simple expansion of the bandwidth. In other words, G_c is the extent to which the logarithmic exchange out-performs a linear exchange, or to which error correction schemes could, in theory, out-perform DSSS schemes.

Figure 7 shows a plot of G_c (dB), as given by equation 8 for various values of the bandwidth expansion factor n and as a function of the "output signal-to-noise ratio". This last, perhaps, requires a little clarification.

Equations 7 and 8 showed a dependence of G_c upon an initial arbitrary reference signal-to-noise ratio r_0 and the bandwidth expansion factor n. Now since we are concerned with theoretical bounds on performance we may make the optimum assumption that the effective output signal-to-noise ratio is the input signal-to-noise ratio multiplied by the processing gain. The epithet "effective" is used so as to cover two types of optimum receiver. The first is one in which an analogue output is obtained which literally exhibits the enhanced signal/noise ratio as described. The second is one in which the output is reconstituted data having a bit error rate which, for the chosen modulation technique, corresponds to that enhanced signal-to-noise ratio.

With this assumption, and reverting to equations 7 and 8, we may now let r_0 be also the *output* signal-to-noise ratio for the reference system which by definition must have unity processing gain (0dB). Hence in Fig. 7, the abscissa corresponds to $10\log_{10} r_0$.

It is convenient to relate the gain to the output signal-to-noise ratio in this way since, from experience or from standard analytical results, we can assess error rates and/or the utility of the system from this. Thus, for most purposes, the threshold of acceptable performance corresponds to an output bit error rate of between 10^{-2} and 10^{-4}, and for almost all practical modulation schemes subjected only to additive gaussian noise, this corresponds to an output signal-to-noise ratio between about 4.5dB and 15dB.

Consequently, when considering the advantages attainable by coding, we may restrict our attention to that region: for it is not really of much use to have, say, a 10dB enhancement of signal-to-noise ratio if the system is working in a region where the error rate is so low that one would not notice the enhancement. Equally, whatever processing gain is achieved is of little avail if the output error rate is still unacceptable.

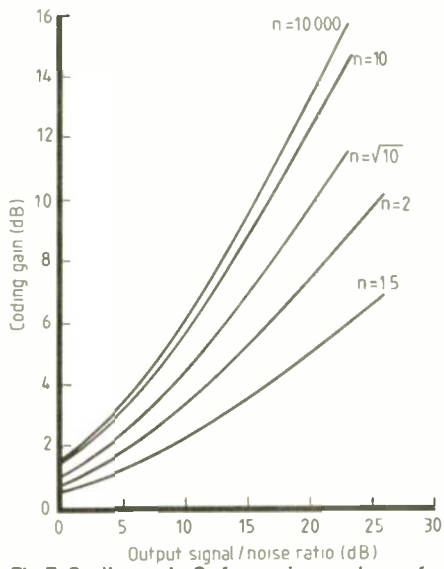


Fig.7. Coding gain G_c for various values of the bandwidth expansion factor n.

With these considerations in mind, it is instructive to examine Fig.7 in some detail. We first notice that relatively small increases in the factor n, when n is itself small, give rise to significant increases in coding gain. For example, for 10dB output signal-to-noise ratio, a change from the reference system (n=1) by only 50% to n=1.5 allows a coding gain of 2.28dB (in addition to the 1.76dB due to the linear exchange). A further increase by a factor of 2.1 to n=10 permits a further coding gain of 2.28dB (in addition to a further 3.22dB due to the linear exchange).

In contrast, for the same 10dB output ratio, an increase in n by a factor of 1000 from n=10 to n=10 000 allows only a 0.4dB coding gain (in addition to the 30dB due to the linear exchange). The reason for this phenomenon is clear. For 10dB output ratio, a value of n much greater than about 10 implies that the *input* signal-to-noise is much less than unity (negative dB), and hence that the logarithmic and linear exchanges are almost the same. That is, the coding gain G_c is small. For n less than 10, however, the implied input signal-to-noise ratio is greater than unity, so that the difference between the logarithmic and linear exchanges is appreciable.

This gives rise to the concept of a "practical ideal" system, in which a linear exchange is sought (e.g. by use of spread-spectrum techniques) to bring the worst-case effective output signal-to-noise ratio to about −6dB and then a further logarithmic exchange is sought (by error correction schemes) to recover the remaining 10.5 to 21dB required for satisfactory operation. This is a concept of coding within coding.

It is worth noting that for large values of n and for output signal-to-noise ratios of 10 to 15dB, coding gains of between 6 and 9dB are potentially available (in addition to the $10\log_{10} n$ dB due to the linear exchange).

IMPLEMENTATION

We shall now consider, in general terms, how one might attempt to achieve such performance. But before doing so, we should emphasise the underlying equivalence of bandwidth expansion and redundancy. Thus for a given improvement in performance in terms of bit error rates for example, we may either retain the same information rate and provide redundancy by increasing bandwidth; or we may *reduce* the information

rate and then provide redundancy to restore the bandwidth to its original value. From the point of view of coding gains, error rates and the like, the two schemes are identical. As practical communication systems, however, they are very different; but since we are here concerned only with the effects of redundancy, we deem them wholly equivalent.

To simplify the presentation I shall confine my discussion to binary data systems; and for the present I shall restrict it to systems in which, at the receiver, each bit is individually evaluated as 0 or 1 and the resulting binary sequence forms the raw material for error correction and detection. Such schemes are called **hard decision** schemes since a firm or "hard" decision is made on each received bit *before* the data is decoded.

The reader, by the way, may have encountered what I call the "bureaucrat's delight" principle of information theory: that decisions should be delayed until the last possible moment – see the final article. It follows that hard decision systems, which essentially make decisions on each bit as it arrives, are non-optimum. They are, however, often rather easier to implement and historically were the first to achieve widespread application.

SINGLE PARITY

All error correction and detection schemes involve the use of redundancy; that is to say, the *effective* repetition of information. However, this does not necessarily imply *actual* repetition. For example, a single parity check bit provides redundancy. Thus, if we have, say, a seven-bit binary sequence of 1s and 0s (e.g. an ASCII character), we may add an eighth bit so as to make the total number of 1s odd (odd parity) or even (even parity). The choice is fundamentally irrelevant, though for some systems there may be small advantages in one or other. For example, choice of odd parity implies that an all-0 sequence is inadmissible, which is convenient to exploit in some instances.

Ignoring any extra bits required to establish frame sync or character sync, (which would be necessary for both systems) our simple parity scheme involves one additional bit for every block of seven "information" bits in the reference system. The bandwidth expansion factor in this case is $8/7 = 1.143$. As a result of such expansion, and assuming that the transmitter power and the information rate are unchanged, each bit is transmitted with less total power (by a factor of 7/8) than in the reference case, and has to be detected against a larger noise power (by a factor of 8/7) due to the increased receiver bandwidth. Thus the bit error rate resulting from adding redundancy is increased. Provided, however, that the correction/detection capability of the coding system more than compensates for this increased error rate, the coding is worthwhile.

Single parity bit schemes do not normally provide scope for error correction, but permit *detection* of an odd number of errors. An even number of errors would leave the parity "correct"; but such schemes are used chiefly under conditions in which the bit error probabilities are very small and the probabilities of two or more errors in a block are negligible. Nevertheless, in many systems bit errors are due primarily to brief bursts of noise (or equivalently, to brief fading of signal strength). In such instances, provided the noise bursts or fading periods are shorter than a bit period, even single parity schemes can be used for error *correction:* if the parity of the received signal is incorrect, and if one can detect one particular bit for which reception conditions were "abnormal", one may surmise that this is the bit in error, logically invert it to restore parity, and output the amended data. Such a scheme is known as Wagner coding after its inventor; and it is a curious, though by no means unique, exception to the more general rules of error correction which normally assume that there is no *a priori* reason to distinguish between bits regarding their susceptibility to error. In other words we usually assume that the source of all errors is, or is equivalent to, additive gaussian noise.

There are some special codes which have been devised specifically to deal with errors which occur in bursts, a common phenomenon in practical systems. Many of these can give enhanced performance if combined with information (such as is used in Wagner coding) as to those bits or symbols which are especially likely to have been subject to error. Their discussion is outside the scope of this series; but if you are interested in pursuing the matter further, you should consult any standard text on error-correcting codes and particularly the sections on Fire codes and Reed-Solomon codes. However, for reasons which will be given in my concluding article, most such codes are rarely used. A major exception to this is provided by Reed-Solomon codes which are effective against both bursts and uniformly distributed errors and are becoming increasingly popular.

REPETITION

Reverting to the main theme of this article, we here assume, as implied above, that the only evidence that any particular bit is more likely to be in error than any other is derived from the structure of the code itself.

On this basis, a single parity bit can only *detect* errors, and can detect only an odd number of errors, since an even number would leave the parity unchanged. Single parity is therefore the most primitive error detection coding scheme, capable in reality of detecting only single errors in each block, since if the error rate is such that there is any significant probability of two or more errors occurring then it cannot be relied upon at all.

Any scheme which applies redundancy to discrete blocks of data in this sort of manner is known as a "block coding" scheme. There are other types of codes such as convolutional and punctuation-free codes which are not necessarily block codes at all; these too are outside the scope of these introductory articles.

Before considering more sophisticated block codes for error correction I shall briefly discuss the other extreme of actual data repetition, which in many implementations is also a block coding system.

ARQ REPETITIONS

If the probability of receiving a message in error is p and we have J messages to send, then after sending them we shall on average find that pJ have been received incorrectly and must be sent again, making a total of J(1+p) transmissions so far. But a fraction p of these pJ repeats (i.e. p^2J) will be received in error and so will need to be repeated, making a total so far of $J(1+p+p^2)$ transmissions. For a determination of average performance we must assume that J is very large and hence that this process needs to be continued a very large number of times overall. Thus the total number of transmissions required will be

$$J(1+p+p^2+p^3+.....) = J/(1-p)$$

Repetition is a very old concept for correction in the case of two-way communication systems. We all instinctively invoke it if we fail to understand some spoken information. The word "pardon" is commonly used as a request for repetition in such cases.

In data communication systems, some form of error detection scheme (such as a single parity bit) is required if the receiver is to request repetition. Then when an error is detected, a request for a repeat is issued automatically. Such systems are called Automatic Repeat reQuest systems, or in the technical jargon, ARQ systems. They are very efficient provided the probability of error is very small; that is to say, provided that the error detection scheme is not too complex (e.g. does not itself involve too much redundancy) and the time spent in requesting and receiving repeats is a very small fraction of the total transmission time. On the other hand, their efficiency drops dramatically as the error rate increases (or if the transmit-receive delay time is long, as in the case of communications with spacecraft).

ARQ involves overheads in the form of time and channel capacity necessary to make the requests and to implement the housekeeping system required. These overheads can be quite considerable when ARQ is frequently invoked. But, ignoring these factors for a moment, if p_m is the probability of a *message* error (only groups of bits or "messages" are normally repeated), then the average number of repeats required for a group of J messages is $j = J/(1-p_m)$ – see box.

Thus if p_m is less than, say, 50%, then ARQ could conceivably be more efficient than a more sophisticated error correction scheme with 100% redundancy (n=2). However, this ignores the overhead factor. This factor can be potentially small for long messages and very high for short messages. On the other hand, the error probability p_m will be much higher for long messages than for short ones. For example, with a bit error rate of 1 in 10 000, the probability of an error in a message of eight bits is 0.08%, but the probability of an error in a message of 1600 bits is 14.8%. If p_m becomes too large there is a significant probability that the repeat will itself have to be repeated, though this is taken into account in the above formula.

It is apparent that when p_m greatly exceeds 0.5 the system is unlikely to be viable

even if the overheads are negligible, a condition which is itself unlikely to apply in these circumstances. As an example, with a bit error rate of 10^{-3} and a message length of 1600 bits, the message error probability p_m will be 80%; so that on average, each message will need to be repeated five times, equivalent to a bandwidth (or time) expansion factor of n=5 in addition to any overheads. Other techniques could achieve good performance under these conditions with a much smaller time or bandwidth penalty. (It is clear that time and bandwidth are linearly interchangeable since repetitions can be made serially, using just one channel, or in parallel, using two or more channels.)

The preceding discussion should have clarified the main issues and explained the difficulties of making definitive statements on the operability of ARQ systems. Clearly they become increasingly unattractive as the bit error rates increase.

Finally, although it is one of the oldest correction schemes, ARQ shares with some of the most modern schemes the property of being "adaptive". That is to say, the amount of redundancy employed is not fixed, but adapts itself to the reception conditions.

FORWARD ERROR CORRECTION (FEC)

ARQ is a scheme for providing corrective redundancy adaptively, on the basis of observed errors. We now consider schemes for providing redundancy in advance (usually on a non-adaptive basis). These are called forward error correction (FEC) schemes. They have the disadvantage that the redundancy is always provided even when it is not necessary; but the advantage that no return link or "handshake" is necessary, and within the capabilities of the coding, correct messages are output with minimum delay.

Again, before considering more sophisticated systems, I shall briefly discuss simple data repetition, but this time without request.

DATA REPETITION

In general, simple data repetition schemes involve repeated transmission, and, in the case of hard decision decoding, "majority voting". The majority vote can be applied to blocks of data such as characters, or to each information bit. The latter is more powerful and is usually adopted in practice.

We shall here assume that the "voting" is applied to each bit. Clearly, if a data bit is transmitted an even number of times there is a possibility that, at the receiver, half of the samples represent a "one" and the other half a "zero". In this case the receiver will be uncertain as to which to choose and for this reason most (but not all) repetition schemes employ an odd number of repetitions.

Thus, in general, a technique of this type involves at least a three-fold redundancy and hence bandwidth expansion (or data rate reduction) by a factor of at least three. Such expansion (or reduction) is frequently unwelcome, so that more subtle approaches are often preferred. However, when bit error rates become very high (e.g. 20% or more) simple repetition may be as efficient as or even more efficient than these other approaches.

In fact, systems have been designed which use repetition to reduce such error rates to levels at which further, more subtle coding can be effective. This implies "coding within coding", rather as I suggested coding within DSSS in the earlier sections of this article.

Suppose the bit error rate is p and that each bit is repeated 2n+1 times; then with majority voting on a bit-by-bit basis the output bit error rate (see upper box) will be

$$p_e = \sum_{r=n+1}^{2n+1} {}_{2n+1}C_r\, p^r (1-p)^{2n+1-r}$$

The table below shows the output error rate p_e as a function of p for various values of 2n+1.

Clearly, when error rates become large, very considerable redundancy is required to produce much improvement. (Incidentally, for those unfamiliar with bit errors, the highest possible bit error rate is 0.5 – see lower box.)

In most practical cases a very large redundancy factor is unacceptable, but there is at least one type of system where it may often be encountered. This is the case in which, for example, a radio channel is wholly occupied by a data system. A good example is a military VHF radio system which may typically carry binary data at 16kbit/s. This may be used for digitised speech for example, but in some conditions the users may be prepared to use data at rates as low as 50bit/s. Clearly, one could repeat 50bit/s data 320 times with a 16kbit/s transmission, which would give extremely powerful error correction. In fact, majority voting on a 319-fold repetition, even for an input error rate of 45%, would give an output error rate of 3.66%. At an input error rate of 40% this would be reduced to 0.015% and at 35% to 2×10^{-5}. For binary signalling schemes such as frequency shift keying (FSK), commonly used in such applications, error rates of 45% and 35% correspond respectively to signal-to-noise ratios of the order of −6.7dB, −3.5dB and −1.5dB.

In the first part of this series we considered a bandwidth expansion scheme in which the same data was sent in parallel in a number of frequency channels. I pointed out that that particular approach gave a linear exchange of bandwidth for signal-to-noise ratio but that it was not a very practical implementation of a spread spectrum sys-

ERROR RATE WITH MAJORITY VOTING

If the bit error probability (often called the bit error rate or ber) is p then p is the probability that any particular bit is received in error and (1−p) is the probability that it is received correctly. The probability that in a message of m bits a particular set of r of them will be received in error and the remaining m-r received correctly is $p^r(1-p)^{m-r}$. If the number of ways in which groups of r can be selected from m is ${}_mC_r$, then the total probability that exactly r bits are received in error is

$$P(m,r) = {}_mC_r\, p^r (1-p)^{m-r}$$

The probability that an m-bit message will be received with s or more bit errors is therefore

$$\sum_{r=s}^{m} {}_mC_r\, p^r (1-p)^{m-r}$$

With majority voting, an output error will occur if more than half the repetitions are incorrectly received, so if m=2n+1 the output error probability is given by letting s=n+1 in the above with m replaced by 2n+1 (${}_mC_r = m!/[r!.(m-r)!]$ where r! means factorial r and r!= 1.2.3.....r. with 0!=1; thus 5!=1.2.3.4.5.=120).

BIT ERROR RATES

The probability that a bit is received in error cannot exceed 0.5 because it we imagine for a moment that it does, we merely have to invert it to improve the error rate to less than 0.5. An alternative way of looking at this is to note that on average, any purely random sequence of bits will have half of them *in agreement* with any selected message sequence of the same length. In other words, if half the bits are in error there need be no connection whatsoever with the transmitted message. This is exemplified in table 1 by the last row, where for an input error rate of 0.5 the output error rate is also 0.5 regardless of the number of repetitions. However, no such constraint applies to other probabilities such as message error probabilities. This is quite consistent with the above since, as I have indicated, if half the bits in a message are in error the message could be a purely random one, thus giving a *message error probability* of almost unity! In fact, in this case, if the message contains n bits, there will be only one chance in 2^n of the received message being "correct", and so the message error probability will be $1-2^{-n}$.

Table 1: majority voting. Output error rate for various numbers of repeats.

	Number of repeats								
2n+1	3	5	7	9	11	19	29	39	79
0.05	0.007	1.2×10^{-3}	1.9×10^{-4}	3.3×10^{-5}	5.8×10^{-6}	1.2×10^{-12}		Negligible	
0.10	0.028	8.6×10^{-3}	2.7×10^{-3}	8.9×10^{-4}	3.0×10^{-5}	3.9×10^{-6}	2.0×10^{-8}	1.0×10^{-10}	Neg'ble
0.15	0.061	0.027	0.012	5.6×10^{-3}	2.7×10^{-3}	1.4×10^{-4}	4.1×10^{-6}	1.0×10^{-7}	Neg'ble
0.20	0.104	0.058	0.033	0.020	0.012	1.6×10^{-3}	1.4×10^{-4}	1.3×10^{-5}	1.2×10^{-9}
0.25	0.156	0.103	0.071	0.049	0.034	8.9×10^{-3}	1.8×10^{-3}	3.7×10^{-4}	9.0×10^{-9}
0.30	0.216	0.163	0.126	0.099	0 078	0.033	0.012	4.3×10^{-3}	9.8×10^{-5}
0.35	0.282	0.235	0.200	0.172	0 149	0.088	0.048	0.027	3.1×10^{-3}
0.40	0.352	0.317	0.290	0.267	0 247	0.186	0.136	0.102	0.036
0.45	0.425	0.407	0.392	0.379	0.367	0.329	0.293	0.264	0.186
0.50	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500

tem. Now sending the same data simultaneously in several channels is conceptually identical to repeating the data; and so one might expect that a redundancy factor of, say, 319 as considered above, might yield an improvement of the order of $10\log_{10}319$ i.e. 25dB. But binary signalling techniques such as FSK typically give quite negligible error rates (less than 10^{-7}) at say 15dB signal-to-noise ratio, and with 319 repetitions one might expect excellent performance at (15−25)=−10dB signal-to-noise ratio. So why do we get such performance only at about −1.5dB with a rather dismal performance even at −6.7dB? The answer lies in the means of utilising the repetitions.

You may recall that in the parallel channel system described in the first article, I made a point of combining the outputs of all channels *coherently*. That is to say we got them all coincident in time and phase before adding them linearly and then extracting the information from the combined signal. The spread spectrum system described in my second article effectively combines all the energy in the wide transmission bandwidth coherently into the narrow information bandwidth at the despreader output prior to extracting the information. With the repetition scheme and majority voting however, we are effectively combining outputs *incoherently*. It is as if, in the parellel channel system, we were to demodulate each narrow band channel independently and then perform majority voting. Because of the low signal-to-noise ratio in each channel, each output will have a high error rate, so that even with the power of a 319-fold repetition the result is still far short of that attainable with coherent addition.

OTHER FEC TECHNIQUES

Virtually all other FEC techniques use parity checks in some form or other and this implies the generation of redundant bits from some sort of logical function applied to a block of data. Note, however, that the input bits to this logical function may include not only the information bits but also the redundant bits themselves. Thus a common technique for generating block error-correcting codes is to start with a block of information bits and enter them into a binary shift register with "taps" at various stages. The tap outputs are fed to a logical combining network (usually exclusive-or gates) and the resulting output used to provide a redundant bit, which may, of course, change with each clock cycle. Often these bits are fed back as input to the register so that it becomes a feedback shift register similar to that described in the second article for generating m-sequences. Such schemes lead to codes with cyclic properties which are therefore known as cyclic codes.

Although we have considered code generation in terms of shift registers, equivalent procedures can be implemented in software on digital computers and with the advent of cheap and powerful microprocessors this is now the most common method, except where extremely high bit rates are involved.

The study of codes involves some quite subtle mathematics, usualiy invoking the theory of Galois Fields, and I shall not discuss this here. Instead, I shall consider one or two simple examples in a small amount of detail and merely mention some examples of other types of coding.

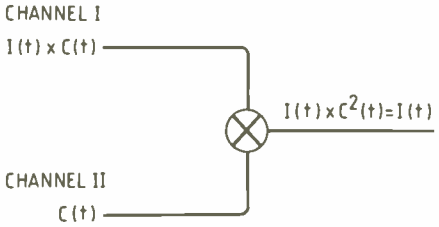


Fig. 8. One of the very early ideas for direct sequence spread spectrum (DSSS) was the so-called transmitted reference system, in which problems of signal acquisition and code lock were avoided by transmitting the spreading code also, on another channel. These schemes gave, theoretically, an improvement by a factor $n^{1/2}$ instead of n. Thus for n=319 they would have given 12.5 dB rather than 25 dB improvement; but you will notice from Table 1 that the majority voting scheme does better than this.

BLOCK CODES

One of the earliest examples of a block code was the Hamming single error correcting code. This code employs a block of four information bits to which it appends three parity bits, making a total code block length of seven bits. It is usually important in code design that parity checks complement but do not duplicate each other. The Hamming single error correcting code is constructed as follows (though the ordering can clearly be changed):

- Bits numbered 3, 5, 6 and 7 are information bits.
- Bit 1 gives a parity check on bits 1, 3, 5, and 7.
- Bit 2 gives a parity check on bits 2, 3, 6, 7.
- Bit 4 gives a parity check on bits 4, 5, 6, 7.

On receipt, we perform the parity checks on the received word in the above order. In other words we check the parity in succession of bits (1, 3, 5 and 7), (2, 3, 6 and 7) and (4, 5, 6 and 7), indicating correct or successful parity checks by a 0 and unsuccessful checks by a 1. These bits then form a three bit word which is called the "syndrome", since it is indicative of the "disease". In the case of the Hamming code as described above, this syndrome, if interpreted as a binary number, gives the number of the bit in error. Hence all we have to do to correct the data is to invert that particular bit and then extract the information bits (3, 5, 6 and 7) from the amended word.

The above Hamming code is particularly simple in this respect and most syndromes are not so readily interpreted. In fact, since the Hamming code checks every one of the seven bits it is clear that it will permit correction whichever four bit positions are chosen to represent the information. These positions are therefore chosen so as to ease the encoding and decoding. That is, they are chosen so that each parity bit is immediately calculable from the data bits, or in other words, each parity bit involves three information bits. If different positions were chosen for the data bits, parity bits would depend partly on some data bits and partly on other parity bits. Thus if bit number 7 became a parity bit, its determination would involve some iteration (or trial and error) since it would be involved in, and would itself involve, all the other parity bits.

Note, however, that if two or more bits are in error, the system falls apart and is likely to result in even more bit errors in the output than we started with. This is the Achilles heel of block error correcting codes with hard decision decoding: they have a strictly limited error correction capability. Note also that in this, as in most FEC codes, the corrected errors may be in the check bits themselves rather than the information bits. Thus, contrary to some naïve notions on FEC, correction *does not* depend upon the correct reception of the check bits. Finally, we should note that in some coding systems the information bits themselves are encoded and do not appear explicitly in the transmitted code-word. Codes in which the data bits *do* appear explicitly are called systematic codes.

Here I should mention that the reciprocal (1/n) of what we have hitherto termed the bandwidth expansion (or data compression) factor n, is – in the case of FEC systems – called the rate of the code. Thus the rate of the Hamming code discussed above is 4/7.

CODEWORD DISTANCE

If a block code or "word" contains a total of n bits of which k are information bits it is described as an (n, k) code. If this code is capable of correcting up to s errors it is sometimes called an (n, k, s) code. Clearly there are 2^n possible words of n bits, but only 2^k are legitimate codewords. Hence for *each* legitimate codeword there are 2^{n-k} possible *received* words. Now consider the complete block of n bits, there are ${}_nC_r$ ways in which precisely r errors can occur. Hence the number of ways m(s) in which s or fewer errors can occur is:

$$\sum_{r=0}^{s} {}_nC_r = 1+n+n\,\frac{(n-1)}{2}+n(n-1)\frac{(n-2)}{6}+$$

$$\ldots\ldots+\{n(n-1)\ldots\ldots(n-s+1)\}/s!$$

Note that for large n and likely values of s, i.e. $s \ll n/2$, the last term dominates so that $m(s) \simeq n^s/s!$

If the code is to be capable of correcting up to s errors, then each of the m(s) possibilities must be uniquely defined by one of the 2^{n-k} "illegitimate" words. It is therefore necessary that $2n-k \geq m(s)$.

Note that codes for which the equality sign applies are called "perfect" codes. The Hamming (7,4,1) code described above is therefore a perfect code since n=7, k=4, s=1 giving n−k=3 and $2^{(n-k)}=8$ while m(s)=1+n=1+7=8.

Similarly the Golay (23,12,3) code is described as perfect with $2^{(n-k)}=2^{11}=2048$ and m(s)=1+23+253+1771=2048. Codes which are not perfect, i.e. for which $2^{(n-k)}>m(s)$, can be used to correct or detect *some* instances in which the number of errors exceeds s.

It is often convenient to consider error-correcting codes in geometrical terms. This involves the concept of n-dimensional spaces, but this need not dismay readers whose mathematics is severely limited since, at least at the level required here, the idea is very simple and almost intuitive. We are all familiar with the idea of graphs or two-dimensional spaces in which a point (x,y) is represented by two coordinates x and y. If these are each allowed to assume only the values 0 or 1, (i.e. to represent bits) then the only permissible points on the graph are the origin (0,0) and the points (0,1), (1,0) and 1,1). Thus this set of four points represents all possible two-bit words. We may extend the idea to three dimensions where a point is represented by three co-ordinates (x,y,z) and obtain the set of eight points (0,0,0), (0,0,1), (0,1,0), (0,1,1), (1,0,0), (1,0,1), (1,1,0), (1,1,1) to represent all possible three-bit words.

Suppose now we restrict the "permissible" words to those with odd parity; i.e. to the set (0,0,1), (0,1,0) (1,0,0) (1,1,1). Each of these differs from each of the others in exactly two coordinates; and because only the values 0 and 1 are permitted this means that to move from one point to another one must move a distance 1 parallel to one axis and a further distance 1 parallel to another axis – a total of two movements each of unit magnitude. Each of the above odd-parity three-bit words is therefore described as having a "distance" of two from each of its fellows. One does not need much mathematical skill to extend the idea to n dimensions and to the concept that any two ordered bit sequences of the same length whose bits differ in m positions are at a distance m from each other. (This is often known as the Hamming distance).

In the n-dimensional world appropriate to an n-bit (n,k) code, only 2^k of the possible 2^n points represent legitimate codewords, and any particular bit error on reception will "move" the perceived point a distance 1. If there are s bit errors, the perceived point will be at a distance s from its correct position. If every legitimate codeword is distant 2s+1 or more from every other such codeword then the "correct" codeword will still correspond to the *legitimate* point nearest to the perceived word point, and hence error correction will be possible.

It follows in general that if all genuine codewords differ from all other such codewords by 2s+1 or more bits, then it is possible to correct up to s errors. Conversely, if a code is required to correct up to s errors then each valid codeword must differ from each other such codeword in at least 2s+1 bit positions. Clearly, a good set of codewords will be one for which the distance between all pairs is maximised. This is equivalent to minimising the cross-correlation between members of the set.

ERROR DETECTION

From the above, it is apparent that code sets having a minimum distance M would need to have at least M bits in error before a corrupted codeword would be mistaken for a genuine (but incorrect) one, provided no attempt at error *correction* is made. Consequently one could forego the luxury of correction and instead use the code to provide a powerful error-detection capability. This can be even more valuable than correction in some instances because the error-detecting power of a code is much greater than its correcting power.

An (n,k,s) code can correct only s or fewer errors but can *detect* up to 2s errors. In fact, if used only for error detection, it will detect *any* number of errors which do not result in production of an incorrect valid codeword. Thus for a code set for which all codewords are equidistant by 2s+1, the code will detect *any* number of errors other than multiples of 2s+1.

Thus if it is more important to be sure there are *no* errors than to reduce their number, the detection scheme may be preferable. A possible example is a case of a nuclear alert!

Alternatively, one may adopt a combination of both detection and correction. It is easily seen from the geometrical model above that in general, for a code set of minimum distance M=2s+1, one may correct up to z bit errors (provided z is less than s) and detect any number of errors between z+1 and M−2z−1=2(s−z). If M is even (e.g. M=2m) one may again correct up to z errors (provided z≤m−1) and detect any number of bit errors between z+1 and M−2z−1. This flexibility can be very useful in some circumstances.

In the concluding article the author will consider soft decision decoding and some further oddments of information.

High-resolution frequency counter *continued from page 369*

contains the BCD value of the figure in the result being refreshed. The LSB of the higher nibble is low only if that digit has its decimal point lit. The remaining three bits indicate the range, which the computer must interpret as the exponent of ten by which the result must be multiplied. The highest bit will therefore mean a multipler of 10^6 (MHz) or 10^{-9} (ns), according to the function being measured. On the 1F and pulse ranges this bit indicates mHz and s, giving multipliers of 10^{-3} and unity.

Let us now look at the $\overline{NR}$ output. This is an extra output from the interface to the computer and goes low each time the counter has just made a new reading. The circuit consisting of $IC_{6,7}$ is basically a two-bit delay line. The input to the delay line is the LSB of port PC and the flip-flops are clocked by PA7, the anode drive for the last, non-existent digit. The circuit operates on the following principle.

Throughout any one complete measuring cycle the sequence of data put out on PC as PA sends its lines low in turn remains constant. When the counter obtains a new result at the end of a measurement, the new data sequence on PC is dependent upon the actual result obtained and can not be predicted. PA7 drives no digit however, and the microprocessor of the counter is able to guarantee that the data on the LSB of PC, when PA7 is active, will change state from one measuring cycle to the next. It is this transition that we detect.

The negative edge of PA7 clocks PC0 into the first flip-flop, and the positive edge copies it into the second. In the interval between these two edges then, the first flip-flop holds the new value of PC0, while the second holds the value from the previous refresh cycle of the display which occurred about 6.5 ms ago. The ex-Or gate connected to the output of the flip-flops can therefore compare the two samples and will give a high output if they are different. This is inverted by the next gate to produce $\overline{NR}$. $\overline{NR}$ is therefore about 820 microseconds in length, but this may be increased in steps of the same length by clocking the second of the flip-flops from the anode drive lines PA0, PA1, etc. The behaviour of the $\overline{NR}$ line is not to be counted upon in the EVENT and CLOCK modes of operation. The results here change too rapidly for the $\overline{NR}$ signal to have any meaning. Once the computer receives a pulse on $\overline{NR}$, perhaps on its interrupt pin, it may obtain the new result from the display in the course of the next 6.5 ms approximately, by reading each digit in turn via the interface.

Another solution to the interface problem which appears attractive is the use of one of the many single-chip microcontrollers that are on the market today. Some of these have a large number of I/O pins, 20 or more, allowing them to replace the 8255 in the above circuit. The part of the circuit built around IC_2, IC_3, IC_4 and IC_5 can be used unchanged, although it ought to be possible to do away with IC_5. To save on I/O pins, only one line of PA, say PA7, need be monitored. This may be used to synchronize data transfers into the microcontroller as each line of this port is low for a period of 800 – 840 microseconds in turn. The controller could also provide a serial rather than parallel link to the computer, allowing the counter to be placed very remotely from the computer. One controller which looks promising for this application is the 8400 from Phillips. This has 19 I/O pins and an in-built serial interface intended for I^2C bus working. It is available in a 28-pin piggy-back version which allows an eprom to be mounted directly on top of the controller. Although its working is rather leisurely when run with a clock frequency of 5 MHz, its instruction set, being very similar to that of the 8035/39 series of microprocessors, is also suitable for mathematics so that it could perform the necessary data conversion to binary, for example, if this was required.

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PROGRAMMING PRODUCTIVITY

Mr Frost makes a plea for a wider use of easy-to-read software and illustrates his point by indulging his cat

BRIAN FROST

In this article, I set out to highlight the advantages of certain programming languages, particularly for use in real-time control applications using the IBM PC, although much of the discussion also applies to general programming requirements on any system. It is with due humility and not a little trepidation that I embark on such a discussion, since I feel I am liable to unleash the wrath of many programmers who have no reason to be at all unhappy with the programming language and style that they currently employ, but I am hoping that this is outweighed by the benefit of the stimulus and any thought that it may provoke.

My qualifications for initiating such a discussion are hardly academic, since I am primarily a hardware designer (and analogue at that) who has learnt about software over some 15 years of 'on-the-job' training, working on various real-time systems since minicomputers began to become extinct. As did many others, with the rise of microprocessors in the early 1970's I began to use machine code out of necessity and the result was fast, tight programs that seemed easy to debug and which demonstrated time after time that many 'software' problems involving direct control over hardware or mechanics were often related to timing, or simply hardware faults hiding within a software 'cloak'.

As customers began to require a higher level of data presentation and as complete computer systems became available at very low cost, many engineers changed to writing control software using the basic interpreters supplied with these systems, experiencing the advantages of the fast editing, mathematical manipulation and file handling that machine code did not have. However, it soon became apparent that the execution speed of the programs left a lot to be desired and that hardware or machine timing problems which had already been solved during programming would often recur when the addition of more program code slowed the interpreter's operation.

As is now widely appreciated, the advent of the IBM PC family heralded a new era of standardization in computer system design where, for the first time, software companies were able to produce products for one machine without its architecture becoming dated even before the software products had matured. The maturing of the PC technology means that now many popular computer languages have become available in PC format and the user may now choose from a number of implementations rather than having to accept only the limited software tools that were supplied by the computer system manufacturer. With the PC as a platform, it is now a more straightforward task to assess programming languages for use in real-time control (or any programming task of course) and to discuss just how closely any of them can approach an 'ideal' tool for the busy engineer or programmer.

HIGH-LEVEL LANGUAGES

Programming in high-level langauages has changed remarkably over the last few years, with great benefit to real-time programmers. Firstly, languages such as Basic using interpreters now run several times faster than older versions due to better coding and faster hardware (although, interestingly, the change from 8-bit machines to 16-bit types has nothing like doubled speed performance). Secondly, the environment within which the programmer writes the code, runs it and debugs it has matured to provide tools that greatly improve programmer productivity within any one language.

Despite these advances, programmers working on real-time systems find that the 'old' problems don't really change. Software execution speed can often limit the performance of a product, and the difficulty of subsequent maintenance or upgrading of software can be very dependent on the ease with which it was written and its presentation to another programmer reading the listing some time later. Indeed, as the general complexity of software rises in line with the increased expectations of its customers, it becomes increasingly important for bugs not to be created, rather than relying on their later removal.

Before trying to highlight those conditions under which 'good' software has the best chance of being created, the limitations of the English language make it necessary to clarify exactly what is meant by 'good'. I believe that 'good' software can be created in any language and is the result of using as many as possible of the following ingredients, not necessarily in this order.

- The programmer should be very experienced with the particular language.
- The programmer must have a detailed knowledge of the control-system task on which he is working.
- The software being generated must be easy to create and modify.
- The software being generated must be easy for others to read.

This list does not have priorities, and most would agree that known software successes have included at least one of these attributes. In some cases, the definition of 'good software' is hazy since, if an experienced programmer is working with thorough knowledge of the task, then initially the result will be successful software, but software which may be judged poor when given to another programmer, or when re-examined much later when its original features can less easily been seen.

Where it is possible, I now believe that writing software that is easily read should be given great importance, because a case can be made that the other items in the list are

POPULAR LANGUAGES IN USE

MACHINE CODE (ASSEMBLER)
This is the level of programming that is closest to the hardware and processor involved and whose use almost always results in the fastest performance and smallest final program. Used extensively for small control systems, often within eproms, it is used where accurate timing, single-step debugging and 'hand-crafting' combine to achieve very specific software/hardware interactions and where processor systems have little user I/O such as disks, keyboard and CRT. An assembler is used to translate user machine-code mnemonics entered using an ordinary text editor or word-processor. Unless provided from libraries of existing machine-code routines, operations such as mathematical functions and disk handling are not available to the machine-code programmer, since only the processor instructions can be used.

BASIC
The old favourite usually provided with all boxed computer systems and available for all processors in one form or another. It is a good language on which to learn the first programming principles, but the traditional Basic interpreters can limit program structure and are slow with larger programs. The newer Basic compilers used to their capability can give excellent performance.

C
This language is often used as a bridge between assembler programming and the

strongly connected to it. If software is easily read, then it is likely to be easy to write since, given that changes can be made quickly, iterations around the 'write-test-modify' loop are encouraged and converge quickly toward succesful listings.

Again, if the essential features of a piece of software are immediately apparent, the correspondence between the software and the task in hand are also clear. A useful by-product is that any grey areas in the programmer's knowledge of the task are visible to himself, and (vitally important) to others.

The programmer's competence within a given language cannot be aided, except with a combination of tuition and experience, and this is where the choice of language can often become a personal one. Indeed, it is as easy to become partisan about one's favourite language as about one's favourite processor or make of car. However, many programmers are now realising that, if a language is presented within an 'integrated environment', the 'write-modity-test' loops become particularly short, resulting in a boost to productivity.

INTEGRATED ENVIRONMENTS

To programmers, this phrase has taken on the significance that 'what you see is what you get' (WYSIWYG) had for word processors when they became popular a few years ago.

The traditional programming method of using a compiler is based on the so-called 'edit-compile-crash' loop, where a separate editor and compiler are used, with the programmer typing in the program, compiling it, running it and then doing his best to diagnose faults from any resulting symptoms. At best, this process is time consuming because there is constant movement between editor and compiler but, at worst, the compiler error messages can make for a significant amount of referral to manuals and cross-referencing with source code.

'Integrated environments' provide the programmer with everything necessary to produce and test a program in one package. Source code for the program is retained in memory within an editor and can be compiled in a few seconds at a key press. Any errors will be flagged, but will also put the cursor at the erroneous statement to allow immediate editing corrections to be 'context-sensitive' (for example ': *expected*).

When the program is run (another keypress from within the editor), a run-time check allows logical program faults to be highlighted to the programmer in the same way as syntax errors; an example would be trying to use the 11th element of a 10-element array.

Several of these environments also include a 'debugger' that operates at run-time. This is extremely powerful and provides the same facilities as machine-code programmers have had in a monitor. The programmer can single-step instructions, execute instructions up to specific points, execute loops a selected number of times, and all whilst 'watching' variables to see the effect on them. This powerful feature replaces the need to continually insert PRINT statements at strategic places in your code to determine logical faults.

COMPILER *VERSUS* INTERPRETER

When I get a piece of I/O or memory-mapped hardware running, I often turn to a simple Basic interpreter to check it. This is because it is still the quickest way to create the few instructions that can send a value to a defined address. If you type the program incorrectly, or introduce some other mistake, a Basic interpreter is almost uncrashable, since each line is checked as the operations are performed.

However, as most people have found when they try to write control programs using an interpreter, they are painfully slow at a typical speed of around 1ms per program line. This can be irksome when you need to examine a front-panel push-button from within a loop of some 100 lines or so, and you are then amazed for just how short a time someone can press a button. To solve the problem the engineer in us creates wonderful mechanisms to either latch or lengthen such pulses until the program will see them; and of course this kind of problems is the reason that interrupts are so popular. Unfortunately, many find out the hard way that the apparent sophistication of interrupts is bought for the price of careful hardware design – especially in noisy shop-floor surroundings.

Many of these problems slide out of sight if the program can be made to execute faster, and advocates of machine-code have used these very arguments to justify its use. If tamed, the compiler is an excellent happy medium, where 'lines' often take only 10-20μs to execute with a complete program appearing some 20 to 50 times faster than an equivalent Basic program using an interpreter. This speed advantage increases as programs become larger, since compilers do not show the interpreter's dependence of execution speed upon program size.

STRONGLY-TYPED LANGUAGES

In using the early microprocessors for intensive real-time control tasks, I used to be very proud of my machine-code programs and it became a personal challenge to produce code that worked efficiently and elegantly. Occasionally, some of it even worked first time! Any question of whether my productivity could be improved by the use of other tools or techniques would have been regarded in the same way as a slur on a favourite football team, with a strenuous denial and pointing to the success of my existing approach.

The situation that existed then was rather special when viewed with the '20-20 vision' of hindsight. The control systems were relatively small and the performance of one piece of machine code amazed many. Because that code was often relatively small, one programmer could keep its entire structure (if it had any) within his brain for long enough to produce a very elegant result, even though many repeat listings were required during its construction for cross-reference. Even more importantly, continual use of the same machine-code pro-

'high-level' languages. With C instructions it is possible to generate programs that perform in a similar manner to their machine-code counterparts, yet at the same time C has many 'high-level' features and conveniently provides libraries of disk handling, mathematical operations and other commonly required routines. As with machine-code, the level of programming freedom within C can introduce logical programming errors in the hands of the less experienced and the language is not the best for conveying meaning out of listings to those less familiar with its syntax. Despite this, it is probably the language most widely used by experienced professional programmers working with hardware.

PASCAL
Pascal began as a language for teaching program structure to students, but has now gathered a solid following of programmers who appreciate the error-correcting discipline of its stricter structure and also its high level of readability. Because of its strict structure, it can be more difficult to learn than the more free-form languages.

FORTRAN
Fortran compilers are available for the PC, but their application is, in the main, restricted to scientific processing and running programs brought across from larger mainframes where the language is well established.

FORTH
Forth continues to increase rapidly in popularity, especially amongst real-time users who point to its ease of learning and the direct correspondence between its own instructions and those of its host processor. It has a unique structure that allows the language to be 'extended' by the creation of definitions which allow it to be applied efficiently in place of machine-code, whilst offering high-level constructions. Because of this efficiency, the small size of Forth compilers has allowed several manufacturers to offer processors that contain a 'built-in' Forth optimized on-chip to provide high execution speed. Unfortunately, the readability of its stack-oriented listings can be impaired, for those less familiar with the language, by its syntax.

MODULA-2
This is a development from the Pascal language, with which it shares many instructions, but Pascal's poorly defined areas have been strengthened by standardization. Modular programming has been encouraged, allowing a programming project to be broken down into logical modules, particularly effective where more than one programmer is working on the project.

OTHERS
Other languages are available, but are often specific to areas removed from real-time control, for example disk-file processing, graphics or artificial intelligence.

duced a level of comprehension of his program by the programmer that was far in excess of any meaning conveyed to others by his listings.

Today, that same programmer may only be creating part of a large program suite, where additional tools become necessary to ensure that his work is consistent with that of his team members, but even where he can word unaided it is now unusual for the application to be so straightforward that machine-code is as appropriate as the other options that are available. Rather the pressure now is to produce sophisticated results quickly, not relying on de-bugging, but writing bug-free code.

Putting aside science-fiction computers to which the programmer can say "write me a program", present-day programs that are closest to aiding the programmer to write bug-free code do so by being 'strongly-typed'. In other words, their syntax checking is so strict that, at first sight, much programming ease seems to have vanished. By contrast, Basic is 'freely-typed', allowing a very free and easy programming style, but also permitting mistakes.

A particularly good example is the use of simple variables in a program. In Basic, a perfectly acceptable program could include

```
100 A_variable = 3
110 PRINT A_varible
```

At first sight this looks correct, but notice that the variable that was PRINTed is not the same variable as was set to '3': the 'a' is missing from the word 'variable'. The result printed would be the value '0', being the value assigned to all fresh variables in Basic. Clearly, subsequent program operations based on that variable would be in error: indeed, as many programmers testify, the effect of such a 'bug' often appears long after its cause! Because the use of long names improves readability within a program, it is obviously desirable to have the program perform some checking on our use of these variables. The strongly-typed Pascal language prevents this happening by requiring that variables are 'declared' before being used. For example,

```
var A_variable : integer; {this is the
                           declaration part}
.
.
A_variable := 3; {now we use it
                  correctly}
Write(A_varible); {and then get it
                   wrong}
.
.
```

Compilation of this program would produce an immediate message highlighting the typing mistake 'A_varible', since it does not agree with any declaration.

Such declarations have other advantages too. As with machine code programming, it forces the programmer to think early about the kind of data that is needed and thus to create variable types appropriately. For example a screen column position variable does not require 15-digit floating-point precision when an integer value will suffice. With data types appropriately used, subsequent program bugs that may incorrectly manipulate such data often result in the compiler being able to help in detecting them. For example, shifting four single bits left eight times because bits 0-3 are needed in bits 8-11 might erroneously operate on a wrongly supplied value of (say) 128. The excessive value that would result from the shift would be trapped by the compiler when it checks that the result did not overflow the data type specified (maximum integer is 32767). Ordinary Basic would be quite happy with the result, however excessive its value.

For constructing programs to run on a fixed piece of hardware (the PC), and with significant experience in machine-code and Basic programming, I began to look for a language that would allow me to concentrate less on the detail of programming, but yet would give me as much of the flexibility of machine-code as possible.

The closest that I have achieved to this is Pascal, a choice that I would have rejected vehemently five years ago, had it been suggested. In the manner of all converts, let me try to justify its use to sceptics by means of a real-time control example.

PASCAL PROGRAMS CONVEY 'MEANING'

If you have never used Pascal before the initial appearance of the program is strange,

```
program Cats;

uses Crt;

const
      Forever = False;

function CatIsPresent : boolean;
 var
      Ch : char;

 begin
      Delay(100);
      CatIsPresent := False;
      If KeyPressed then
            begin
            Ch := ReadKey;
            CatIsPresent := True;
            end;
 end;

procedure OpenCatFlap;
 begin
      GotoXY(1,1);
      ClrEol;
      Writeln('Open cat flap');
 end;

procedure CloseCatFlap;
 begin
      GotoXY(1,1);
      ClrEol;
      Writeln('Close cat flap');
 end;
```

```
{-----------------------------------------}
{}    begin                               {}
{}      ClrScr;                           {}
{}      Repeat                            {}
{}          If CatIsPresent then OpenCatFlap {}
{}                  else CloseCatFlap;    {}
{}                       until Forever;   {}
{}                end.                    {}
{-----------------------------------------}
```

Fig.1. Cat-flap control program in Pascal. Even without comments, the meaning is clear.

because of the simple rules that govern its layout. In reality, they are a great aid to creating the structure behind programs that often do work first time.

As you start to write your program, Pascal only knows the commands that are built-into the language, such as screen commands, keyboard commands and mathematical functions. Using these, you create neatly partitioned sections of program that are either 'procedures' (any general piece of program) or 'functions' (pieces of program that always return a result). These procedures and functions are given any name that you wish.

As the program builds up, any of these procedures or functions can make reference to earlier ones, as if by being placed earlier in the program their names had added extra facilities to the language itself. This structure has the effect of placing the main part of the program at the *bottom* of a file rather than – as would seem more logical – at the top. However, this ordering does ensure a program structure that is consistent.

I am not impressed by programs that are structured nicely, but I am impressed when I can read a program listing and understand immediately what is happening; I believe this is the most important single attribute that a real-time control program can possess – for two reasons. Firstly, the discipline imposed on the programmer to create this explanation does ensure that the program has been well thought through rather than having simply been allowed to evolve; and secondly, ease of future maintenance will depend upon the level of clarity that the program can exhibit to anyone, even to its author some time later.

This need to make the program operation 'obvious' is often increased by the chosen language structure hiding any inherent meaning, the only recourse being to add comments to aid the process. The use of machine-code is an example where the instructions used with comments are individually very obvious, powerful and fast, but when used without comments become almost meaningless. Of course, a good machine-code programmer recognises this and generates such comments, but now finds that he has a double burden. Real-time systems very often require optimization during which program timings are changed, low-level drivers are changed or even significant modifications are made to the entire control program in the light of unforeseen hardware/software interactions. These modifications are often accompanied by last-minute panic over the impending visit of the Managing Director or a customer and, in such circumstances, it is natural to leave the task of updating the comments until the

heat has died down and face the attendant difficulties of re-aligning comments with code

For any programming task this burden can be greatly reduced by using code that is 'self-documenting'. This may seem an idle dream, but have look at **Fig.1** which shows the listing of a hypothetical, real-time control system that controls your high-tech, controlled-entry feline-access mechanism (cat-flap). Look directly at the section of the program in the box: it has no comments at all, and yet the meaning is perfectly clear at a glance.

Now have a look at **Fig.2**, which is the same program, but coded in Basic. Although the program has been laid out to separate the subroutines, and comments have been added, the essential program operation is at least clouded.

The secret behind the clarity of the Pascal program in Fig.1 is that any section of program can use names that you have 'created' using smaller sections of program earlier; and these names do not need explicit prefixes such as SUB, GOSUB or CALL. This is very powerful feature and is now accepted as being the closest approach to 'self-documentation' of code. In this language, comments are still required, but far less often and then only when the essential program operation is clouded.

There are several implementations of Pascal now and I can recommend 'Turbo-PASCAL' by Borland, which is offered within the integrated environment mentioned earlier and contains extensions to the Pascal language which allow programmers to use machine-code where the ultimate speed is required. To a large extent, this language has become a *de facto* standard with many libraries of routines available. Anyone who is interested in continuing to learn this or any other implementation of the Pascal language can easily obtain one of the many excellent introductory books available. Adherents of Basic can benefit from Microsoft's Quick-BASIC, which is offered within a powerful integrated environment and offers additional features that make it more strongly-typed. Other languages are now being offered within integrated environments and the development is certain to continue toward the aim of maximizing a programmers' productivity.

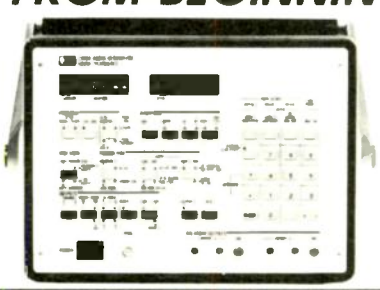
Whilst I am sure that this discussion has not swayed more than a few from their favourite language, the message is to keep an eye on tools and techniques that continue to evolve since careful selection of the right tool can make the task a lot easier.

```
100 CLS
110 GOSUB 1000 REM Test for cat present
120 IF CATISPRESENT = 1 THEN GOSUB 2000 ELSE GOSUB 3000
130 GOTO 110
140 REM
150 REM
1000 REM Tests for cat present. Sets 'CatIsPresent' = 1 if so.
1005 CATISPRESENT = 0
1010 FOR A=1 TO 10000 : NEXT
1020 IF INKEY$ = "" THEN 1100
1030 A$ = INKEY$
1040 CATISPRESENT = 1
1100 RETURN
1110 REM
1120 REM
2000 REM Open cat flap.
2010 LOCATE 1,1
2020 PRINT "Open cat flap "
2030 RETURN
2040 REM
2050 REM
3000 REM Close cat flap.
3010 LOCATE 1,1
3020 PRINT "Close cat flap"
3030 RETURN
```

Fig.2. The same program as shown in Fig.1, but written in Basic; its meaning is to some extent obscure.

AUDIO TESTING

FROM BEGINNING... ...TO END



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Video Frequency Input:	Minimum Voltage: 1Vpp. Impedance: 75 ohm or 10K ohm in case of a through-signal. Connector type: BNC.
Teletext Input:	Voltage: 1Vpp/75 ohm.
Teletext Clock Input:	Voltage: 1Vpp/75 ohm. Measurement: Aperture of eye pattern: linear or Lissajous figures, selectable. Indication: directly on the picture tube. A calibrated scale shows percentage of eye pattern aperture. Error: the instrument introduces an error of ⩽5% with video input and 20% with RF input. Jitter on regen'd clock: ⩽25ns. Line selector: Selection of any TV line between the 2nd and the 625th scanning cycle by means of a 3 digit thumbwheel switch.
Oscilloscope:	VERTICAL CHANNEL: Sensitivity: 0.5 to 2Vpp/cm. Frequency Response: DC to 10MHz. Rise time: pre & overshoot ⩽2%. Input Coupling: AC. Input Impedance: 75 ohm/50pF. TIME BASE: Sweep Range: 20 to 10ms (1.1/2 frames); 32; 64/192us (1/2; 1; 3 lines). Linearity: +/–3%. Horizontal Width: 10 divisions; x5 magnification.
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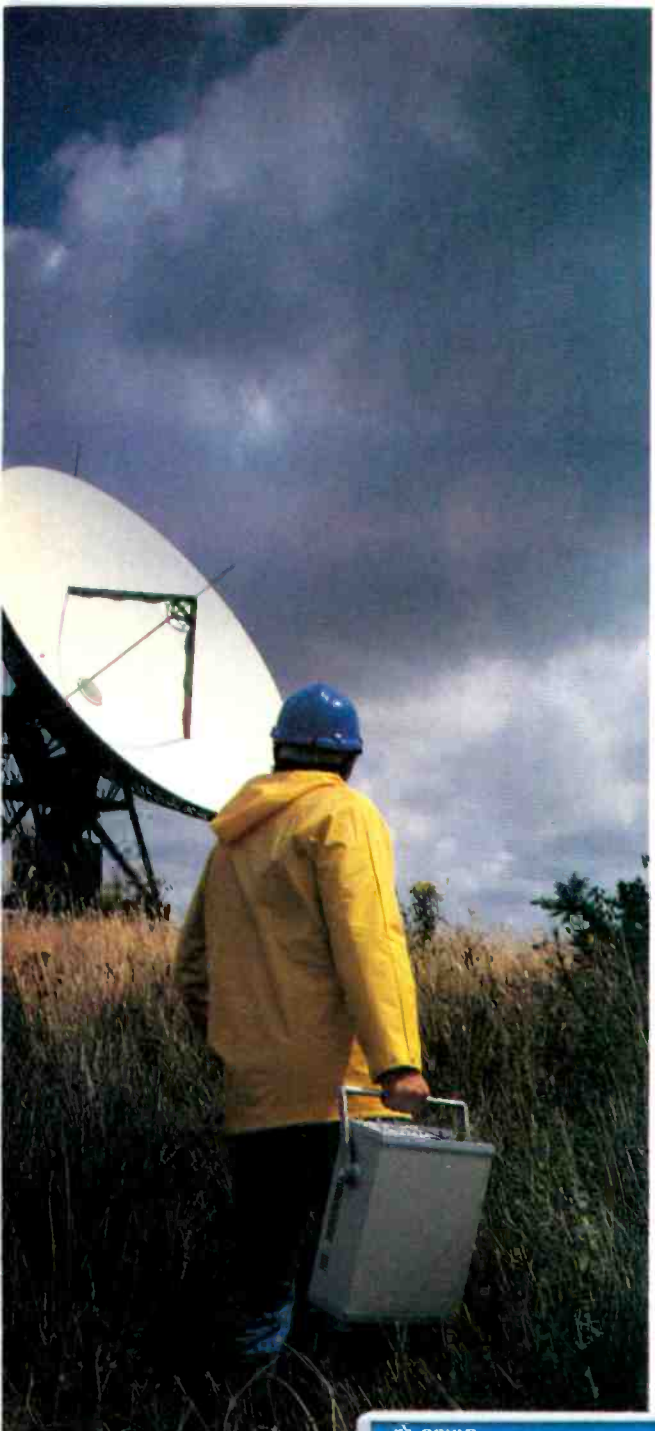

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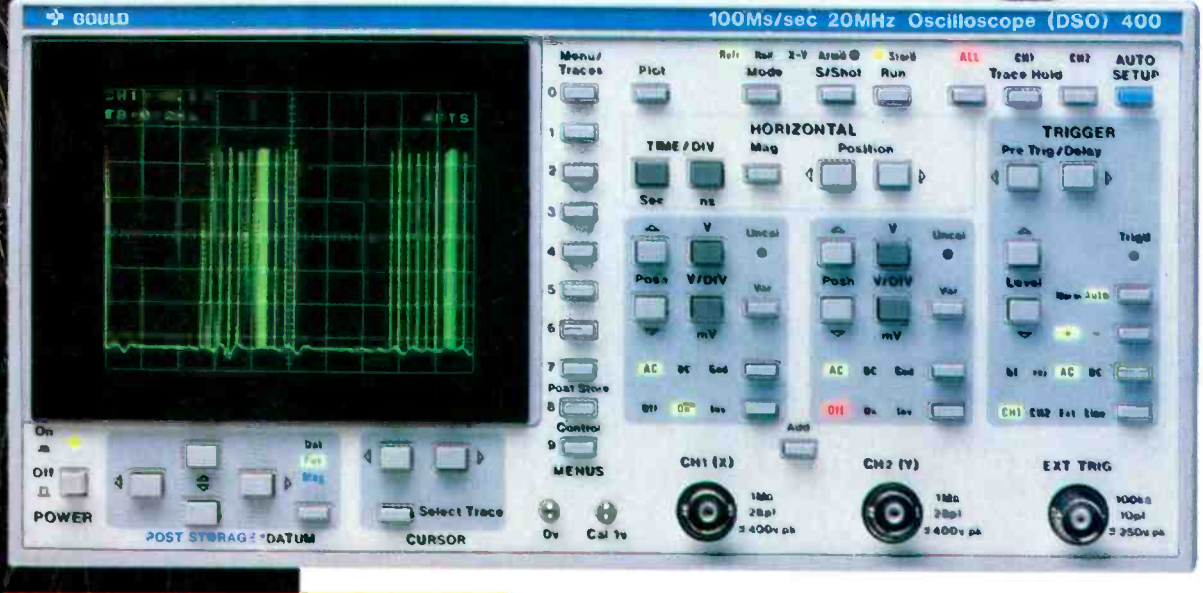

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HOW TO TEST SURFACE-MOUNT CIRCUITS

There is a limit to the ability of present-day automatic test equipment to cope with the continuing increases in the number of integrated circuit packages and in the complexity of integrated circuits themselves. Manufacturers of assembled printed circuit boards use either high pin-count in-circuit test systems or functional board testers or both. Either way, test technology is faced with increasing difficulties as surface-mount technology develops. Besides the high cost of specialised test fixtures, probing is near impossible where components are densely packed.

The way forward was recognised by Harry Blacker of Philips some years ago in initiating the Joint Test Action Group. What was needed was a design structure to be included in all the integrated circuits involved in a product so that it can detect defects, such as those introduced by solder splashes, incorrect components, and open circuits. 'Boundary scan' does just that.

The technique involves the inclusion of a shift register latch next to each component pin so that signals between chips can be controlled and observed using scan testing methods. The paths for boundary-scan cells in the individual i.cs are connected serially to form a path through a complete design. data is either loaded into the scan register from the input port, or driven from the register through the output port.

The Joint Test Action Group has brought together users and IC manufacturers; membership has grown from the original ten to 36, taking in the major ATE and semiconductor manufacturers. The group's specification for boundary scan has been submitted to the IEEE Testbus subcommittee, whose March San Francisco meeting is expected to ratify its inclusion into the P1149 spec and the 1149.1 protocol. (P1149 covers Test bus at the sub assembly and system levels as well as integrated circuits.) Already implemented in custom silicon circuits produced by members of the group, production of semi-custom with boundary scan is at last getting under way now that suitable cell have been incorporated into asic libraries.

Some standard parts have been sampled by Texas Instruments. But what about the rest of the industry's output? How many boundary-scan systems have you seen?

INSIDE

388 **Changing role of digital oscilloscopes** Over the past 12 years developments have made the oscilloscope acceptable in many applications that were previously unacceptable. John Bryan of Gould Electronics charts the features that have made this instrument so successful.

393 **Digital audio testing in the digital domain** Dr Richard Cabot, *en route* from the Hamburg AES Convention, stops off in London to discuss how to make standard audio measurements on digital signals without converting to the analogue domain, and illustrates the techniques with measurements on commercial A-D and D-A converters.

397 **Test structures in wafer fabrication.** Dr Andrew Walton, organiser of this month's Edinburgh IEEE conference on microelectronic test structures, explains how different structures are used to test wafer parameters, and highlights the topical issues in wafer process control.

401 **Wafer-scale kernel testing,** by Ivor Catt. Can faulty circuitry be made to work correctly by pouring in more and more circuitry? Improved reliability in semiconductor process technology means that Catt's Spiral Algorithm – the basis of Insight's cover picture – may be superfluous when products using it finally reach the market.

403 **After modularity and automation, what next?** The newer system architectures – VXIbus and RTSIbus – provide for precise timing at the system level, but there is still a need for a software spec that deals with timing in a top down way.

Cover story. This superposition of a computer-generated display for the routing of 'soft' connections between the 1Mbit rams on this Anamartic wafer is due to Gordon Neish and Neil MacDonald. The photograph, which readers may have first seen in last June's Industry Insight, is reproduced here to mark February's joint Anamartic/Fujitsu announcement of their 200Mbit wafer at the IEEE's annual solid-state circuits conference in February.

The success from this little-known British company – in the face of some spectacular industry failures – is due largely to the alternative, software approach to fault-tolerant wafer-scale integration of Ivor Catt (WW July 1981), and to the foresight of Clive Sinclair at Sinclair Research's Metalab. The wafer memory is also self-repairing, the sp ral routing being formed each time the wafer is powered up.

THE CHANGING ROLE OF DIGITAL OSCILLOSCOPES

During the 1970s a whole new range of sophisticated test equipment came on to the market and in its light the oscilloscope was seen as being primitive and difficult to use. It was not regarded as a measuring instrument in many applications but simply that of a viewing device for the visual comparison of signals. To a certain extent, the oscilloscope of twelve years ago was a primitive device and gave less than satisfactory results on transient or low repetition rate signals.

A major technological advance came in the form of the digital storage oscilloscope which gave a digital representation of an analogue waveform. Users immediately saw the advantages of having a clear, stable display of any waveform and they soon realised that as the signal was now stored in a digital form there was a lot more information that could be gleaned from the signal.

Gradually the move away from the simple digital storage oscilloscope was made as more features were included to increase the use and range of applications. The chart shows how this change has evolved from the simple 'view-only' products to the modern sophisticated instruments used to capture the signal of interest exactly and perform complicated measurement and analysis of the signal.

Significant developments in the past twelve months have made the oscilloscope acceptable in new fields of application – and even more acceptable in existing areas

Overview of user requirements

User needs can be broken down into five main areas

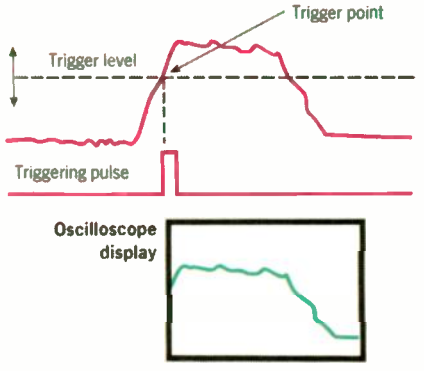
Acquisition	For most users the traditional triggering system is not elaborate enough to cope with modern requirements.
Analysis	Signals captured by a scope are not always in the form needed to understand the measurement.
Measurements	Customers want to measure the range of signal parameters traditionally measured using an oscilloscope, but because measurements are made by eye, accuracy is low and repeatability poor.
Archiving	Providing a permanent record of a scope trace was by using a scope camera is difficult and expensive – users want to be able to transfer traces to remote locations for further analysis.
Automation	Traditional instruments have been labour intensive, needing a skilled operator to use and interpret results. Now the need is for scopes that can be incorporated into computer-driven test systems, and perform series of tests and measurements with the minimum of operator involvement.

This discussion looks at the latest developments in each area.

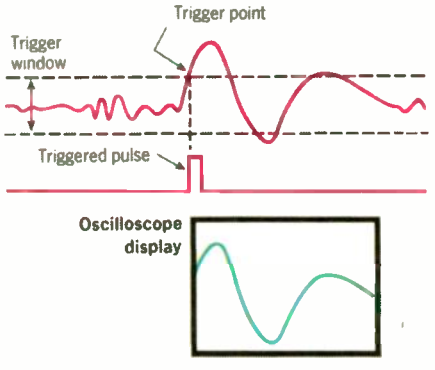
Acquisition

The traditional oscilloscope would only capture a signal if it passed through a threshold in a positive or negative direction. This was later extended to window triggering – where the oscilloscope would capture a signal if the trigger voltage left a pre-defined band. These modes of operation were essentially hardware-based triggering systems. With the arrival of the digital scope, the need for a more sophisticated triggering system was established.

Basically there are two types of triggering now seen as essential in modern oscilloscopes: pattern triggering and variation capture. Both are similar in that they are either capturing a signal which deviates from an established pattern, or capturing variations in a signal – for example drift or glitches.



Traditional oscilloscopes would only capture a signal if it passed through a threshold in a positive or negative direction.



In window triggering the oscilloscope would capture a signal if the trigger voltage left a pre-defined band of voltages.

Pattern triggering

Pattern triggering is a very powerful mode, especially in digital electronics. As most signals are visually similar, it is difficult to find a unique point at which to trigger the scope as all the pulses are identical.

To capture deviations from a pattern, the oscilloscope compares the captured signal against a predefined pattern. If the signal falls within the limits of the pattern the scope will not trigger, but if not it will capture the signal (see diagram).

Mask testing is another type of pattern test where the need is to compare the captured signal with a predefined mask to ensure that

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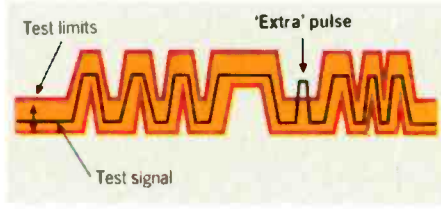
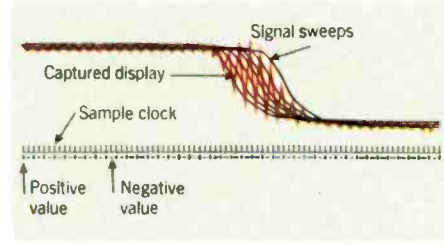
the signal falls within a parameter set. This is common in production testing and the mask is either production – specific, or an international standard.

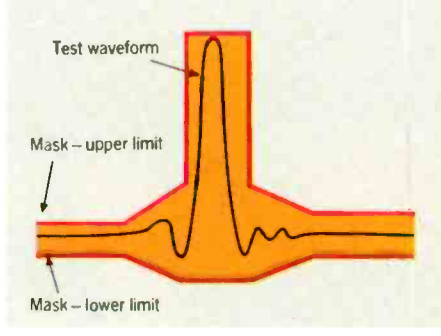
This has been a very labour intensive task and one prone to many errors in both measurement and interpretation. The use of limits testing simplifies this tremendously, as the mask can be defined from a computer and the comparison performed quickly and easily. If there should be a need to adjust the test system, the scope can display a fail message while still performing the test so that it is possible to make interactive adjustments while testing.



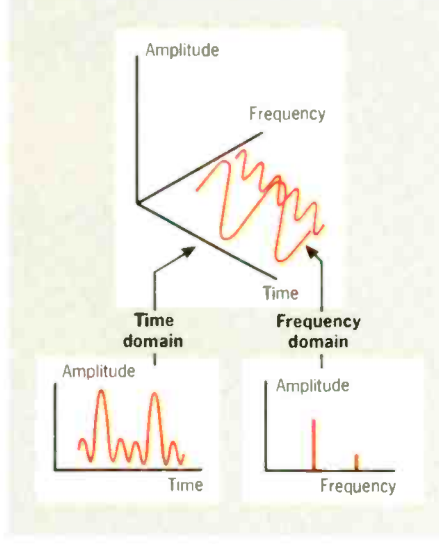
Pattern triggering uses limits testing to capture a glitch within a pattern if it falls outside the pattern limits.



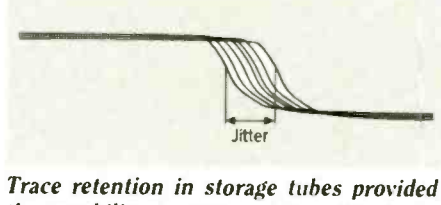
In digitizing oscilloscopes, envelope mode stores the most positive or negative values in alternate memory locations and builds up an envelope over a period.



Computer generation of masks for pattern testing makes for quick and easy comparison as well as interactive adjustment while testing.



In oscilloscopes with a built-in FFT capability for frequency domain display the limited dynamic range 4 dB is adequate for many applications. The Fourier transform is a special case of the discrete transform with points at 128, 256, 512,. . . to increase speed.



Trace retention in storage tubes provided the capability to capture intermittent signals, drift or the envelope of signals too high in frequency to view, functions now provided by an envelope mode.

Variation acquisition

The traditional tube storage oscilloscope provided a capability for monitoring a signal for variations with a variable persistance mode. Here the physical process would retain a trace for a certain time and build up several sweeps – each trace would then fade a certain time after the trace had been written. This provided the capability to capture drift within a signal, intermittent signals or to capture the envelope of a signal where the basic signal components were of too high a frequency to view, see diagram.

This mode of operation was difficult to implement in digital storage oscilloscopes and this type of application was the only one remaining for tube storage scopes. Now this acquisition is catered for by envelope mode, which will build up a trace over several sweeps and then store alternate maximum and minimum values, as shown on this page.

Analysis

There has been a gradual move within the digital storage oscilloscope that has allowed facilities that were once external to the unit to be incorporated into it. External implementation was either via a computer or visual comparison by the operator. The areas of analysis are

– signal transformation
– comparison analysis
– signal processing.

Signal transformation

One of the principal transformations is from the time domain to the frequency domain. The frequency domain shows the amplitude of the signal against the frequency domain rather than the time domain. The most common way to do this is by using the fast Fourier transform (FFT), a special case of the discrete Fourier transform (DFT) which uses an integral power of two points (e.g. 128, 256, 512 or 1024). Because of this, the speed of operation is greatly increased with no degradation of accuracy.

Originally an external computer or a dedicated FFT analyser would be used, but the first solution is inconvenient with two units to move, interfacing problems and software. The second solution could be expensive if all that was needed was a quick look at the frequency domain to examine the extent of the problems without the cost and inconvenience of a separate FFT analyser.

Of course, FFT analysers are essential to make high resolution measurements on wide dynamic range signals, but the vast majority of oscilloscope users will only need the FFT capability infrequently. There are advantages and disadvantages to both – the FFT analyser will usually offer a wide dynamic range (>70dB) with a comparatively slow a to d converter (< 1 megasample/second), whereas the scope will have a lower dynamic range (40dB) but a higher digitizing rate and more powerful triggering.

An FFT facility allows selection of

- the number of points – fewer points give faster results. The disadvantage is that frequency resolution is degraded.
- window function. The nature of the FFT algorithm requires that a transient signal needs a different window function from a repetitive waveform. The window function basically multiplies the captured data points by a function.
- logarithmic scaling. To be able to view both high and low level frequency components it is important to scale the amplitude axis as a log scale.

Comparison analysis

It is difficult to determine whether a current trace is the same as either a previously captured trace or a reference trace. This is easiest if the trace is repetitive and traces can be superimposed, but if the signal is a transient that may not be possible. There can be many changes in the trace that will not affect the comparison, but can make a visual comparison impossible.

Both horizonal and vertical position differences are easily corrected in a digital storage oscilloscope (DSO) as the digital data can be moved. With a conventional scope, a facility such as this is impossible once the signal has been captured. Even differences in

amplitude can be eradicated using post-storage magnification and attenuation which are, again, not possible with a conventional oscilloscope.

Conventional scopes also had difficulty in making easy comparisons between the current trace and one that was previously captured. The only technique that made this possible was the use of a scope camera and to visually compare the two signals – the advent of the DSO overcame this problem entirely.

Traces can be stored in either non-volatile ram or an external computer and then recalled for comparison. To make this comparison simple, trace arithmetic gives the differences between two traces. Coupled with the post-storage shift features, this makes it easy to compare a current trace with one previously captured.

Signal processing

A captured trace can be processed to give the effect of a low-pass filter. The algorithm is formed so that the cut-off frequency varies with timebase range and there are several steps of filtering per timebase range. The immediate application of this is to filter the high frequency noise from a captured signal, an extension being to perform 'What if?' analysis.

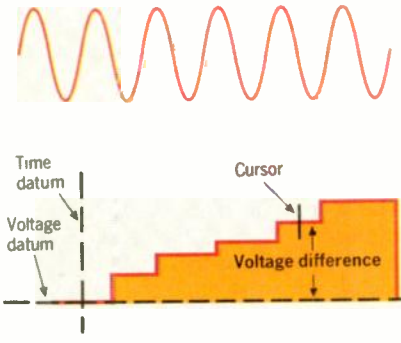
It is thus possible to capture a signal that may need some form of filtering and see the effect that different values of filtering will have on the signal. This means that with the minimum of effort it is possible to obtain a quick preview of the type of effect a hardware filter might have upon the signal – even before it has been designed.

Measurements

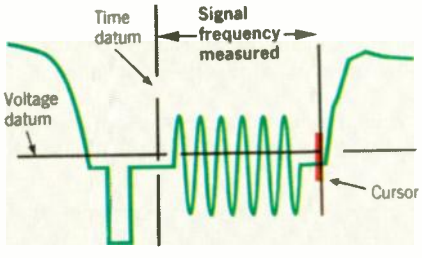
As the basic function of an oscilloscope is to give a time-domain display, the standard measurements are voltage and time differences. To the majority of engineers, the main instruments for these functions are the digital voltmeter and the time-interval and frequency counter. These give excellent results for the measurements of simple waveforms – a DVM can measure voltages with resolutions of nonovolts, and a counter can measure time intervals with resolutions of picoseconds. Problems arise when the waveform is more complex.

The DVM will give a measurement of the overall waveform. It is possible to make several tens of readings per second or, at a lower resolution, several thousand, but it is impossible to make spot readings between points on the waveform, as illustrated. For that particular application a DSO is the best instrument, although it has a lower resolution.

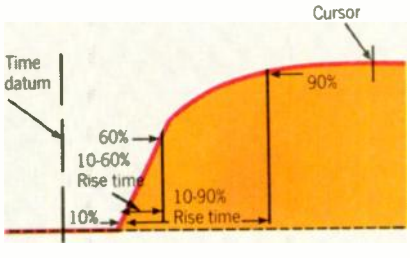
Again, with a counter, the resolution achieved on a simple signal greatly exceeds that obtained on a DSO. It is impossible to make measurements on a complex signal because it's not possible to see which part of the signal is being measured. A DSO makes it possible to select the exact part of the signal to measure.



DVMs are accurate for simple, constant signals but oscilloscopes view the signal and measurement point, and change the reference point after capture.



The microprocessor makes it easy to incorporate routines to measure a wide range of waveform parameters.



Sometimes it is useful to select point other than the 10 and 90% points when measuring rise or fall times.

Simple measurements of voltage and time have been available for a long time and with the arrival of the microprocessor it is an easy task to incorporate a range of routines to measure a wide range of waveform parameters, as indicated on this page.

As signals can be easily viewed, the operator can quickly select the waveform of interest, leaving the scope to calculate the parameters. Rise and fall time have generally been performed on oscilloscopes but they needed a skilled operator and were prone to poor accuracy and repeatability. Today, measurements such as these can be performed quickly and easily. To make a measurement more useful, it is now possible to select different points from the usual 10 and 90% points on a signal.

Other measurements such as area and RMS are not usually made on an oscilloscope These are only possible because of the digital nature of the trace. A scope makes it easier to select the part of the trace to measure and then the processor can calculate the waveform parameters.

The ability to view and select part of a trace makes it possible to contemplate replacing some of the test equipment items such as counters and digital voltmeters.

Archive

Information is stored to have a permanent record of the signal, to monitor changes in a parameter, and for analysis at a more convenient time. A permanent record was usually achieved with a camera. Once a result had been obtained, the display was photographed. Though this method gave good results it could be expensive and didn't easily lend itself to any further analysis techniques. Once the signal was digitized – the number of options increased. The signal could be converted into a slow-speed analogue signal with the output recorded on an analogue X-Y recorder. When low-cost digital plotters appeared on the market, offering colour plots with full annotation, the analogue recorders were superseded.

Digital plotters changed from being external to internal devices giving integral plotting of the captured trace. Again this is faster, more convenient and cheaper than an oscilloscope photograph, but still only gives a record with no further analysis capability.

In terms of analysis there are two requirements: to compare two traces, and to analyse them further. Most digital scopes have a computer interface, but it is not always possible to transfer data to the computer for further analysis immediately. Often signals are captured away from the laboratory and it is not possible to use a computer with the oscilloscope.

To simplify this situation, oscilloscopes can now store several traces for analysis at a more convenient time. In some cases these are automatically saved on the receipt of a trigger signal. When the scope is at a site remote from the laboratory a memory module can be detached and sent back to the main site for analysis on another oscilloscope.

Automation

To make the task of automation easier, most digital scopes can now use their internal processor to provide a sequence of tests and measurements that can be performed automatically. The length of sequence is kept short as there is a limit to the number of separate tasks that can be undertaken before

it becomes more cost effective to use an external computer. An extension to the technique is for the computer to store several sequences and then incorporate them within a larger test program. This approach makes it much easier to write large test programs.

The writing of a sequence should be as easy as possible. The most natural way is for the user to perform the test sequence and the scope to learn it. This is an effective method as the user may know the best way to carry out a task but not necessarily be able to write it down. A sequence can also be entered using the 'Edit' mode to either edit a learned sequence or enter an established one. The main advantage of using a programmable sequence is that it can give the most appropriate amount of automation, without the engineer having to learn how to program a computer.

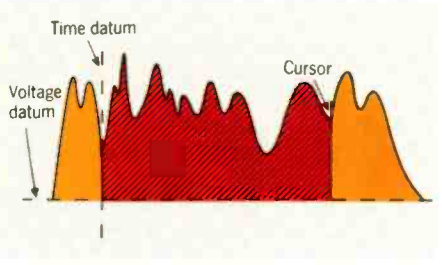
Operator interface

Control for added facilities are provided in three ways – additional front panel buttons, menu functions, a through an external keypad. There are several problems in adding more buttons to the front panel. The trend is to move towards a smaller front panel. Extra buttons add to the clutter and make the instrument more complicated to operate.

The menu system always seems an attractive idea because the extra hardware cost is minimal, particularly when the product already uses a menu system for the operation of the scope. The disadvantage is in the terms of the usability of the oscilloscope. They tend to be used by several people in a particular environmental, and most will be 'occasional' users. The difficulty with menu systems is that no matter how much effort is put into arranging the system – the wrong function is always in the wrong menu!

The external keypad is by far the best solution for many reasons. For the user who only needs the basic oscilloscope features the front panel is uncluttered, but for the user who needs the extra facilities the keypad gives one key per function for ease of use. The unit can also be upgraded when further enhancements to the software are made.

By John Bryan, product marketing manager at Gould Electronics Ltd of Hainault, tel 500 1000.



Digital nature of the trace makes it easy to select parts of waveforms for measurement and calculate areas under curves. It is thus possible to contemplate replacing counters and digital voltmeters, say Gould.

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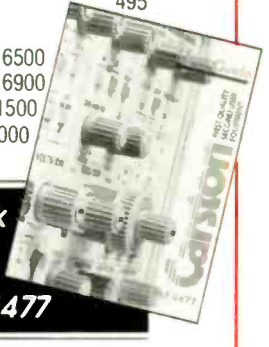

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DIGITAL AUDIO TESTING IN THE DIGITAL DOMAIN

When digital devices perform functions previously available in analogue form they may be tested as black box replacements for the corresponding analogue device using the conventional analogue measurement range of hardware.

However if the device only interfaces in the digital domain, if the purpose of testing is to provide detailed design feedback, or if it performs functions not previously available in analogue form, this approach is not adequate.

To isolate the performance of portions of the device under test designers often employ high quality AD or DA conversion systems to convert their test equipment into the digital domain. This technique also requires, or takes on faith, that the conversion system used to interface to the device under test is of higher performance.

Digital gain can be introduced in the device under test to help separate the effects of conversion achieved by shifting bits of digital words to the left or right by N bits which produces a gain or loss of 6N dB. Any application of digital gain or attenuation limits the dynamic range of the measurements. This approach does nothing to solve the other inaccuracies of conversion: anti-alias and reconstruction filtering, sample and hold problems, deglitcher problems, and clock jitter. Another problem is that some parameters of interest to digital audio designers are difficult to measure in the analogue domain: differential nonlinearity, integral linearity, missing codes, error rates, error correction efficiency and interpolation accuracy for instance.

A means of measuring digital audio signals in the digital domain is required to eliminate these inaccuracies in conventional tests and to facilitate specialized testing. The solution cannot focus solely on the digital portion of the problem since the equipment under test transcends the analogue and digital domains. Audio Precision has developed the concept of dual domain testing, allowing testing of hybrid systems with equivalent methods directly in the appropriate domain.

How to make standard audio measurements on digital signals without converting to the analogue domain

Digital measurement hardware

Audio Precision developed the DSP-1 to make the measurements directly in the digital domain. It provides a digital signal processor core with both analogue and digital input and output capabilities. It is one module in a larger computer-based test system, Audio Precision's System One, which includes conventional analogue measurement hardware. The DSP-1 module provides direct digital measurement capability and enhances the analogue measurement functions of the existing analogue system. It is built around three digital signal processors, one for the DSP core functions, one for the analogue interface, and one for the digital interface. The DSP core and analogue circuitry are on one board, the digital interfaces are on an optional second board.

Digital audio testing was the subject of the March lecture to the British section of the Audio Engineering Society.

Hardware is built around three Motorola DSP56001 24-bit digital signal processors. Program memory is 8K words of 0-wait-state static ram and data memory is 32K words of 1-wait-state static ram. The option board adds another 64K words of static data ram, split equally between X and Y memory. The main board also contains a hardware random number generator and simple real-time clock.

The decimator DSP receives signals from two on-board converters and decimates the data to lower sampling rates. The ADCs are always run at 192Hz or 176.4 kHz and reduced if desired by decimation filtering to 48, 44.1 or 32 kHz. Analogue signals from the various portions of the System One measurement modules or from dedicated front-panel inputs are routed to 80kHz anti-alias filters before feeding the A D converters.

The third processor is for serial audio communications over an AES-EBU format port. Data encoding and decoding, synchronization, parity checking and extracting the serial status bit stream are accomplished by dedicated logic circuits. The additional DSP provides sample counts, time-of-day clock, pre-emphasis flags, channel allocation information, and source and destination codes. Additionally, it pre-emphasizes and de-emphasizes data from this interface via recursive (IIR) filters.

Parallel input and output ports are also provided for connection to external test circuits and DSP devices. Each port handles two channels of 24-bit data.

Dual Domain Testing®

To allow comparisons between signals at arbitrary points in a digital audio device requires that the measurements be made digitally in a manner similar to that in the analogue domain. Suppose an unacceptably high value of THD+N is measured at the analogue output of a digital tape recorder. A measurement of distortion on the digital signal out of the recorder will indicate whether the problem is in the record or reproduce sections of the machine. However, measuring distortion with an FFT of the

digital data will provide incomplete results since it cannot be correlated with the reading on the analogue signal. To avoid this problem the measurements in the two domains must be made with comparable methods.

By downloading signal processing code to the DSP module for the desired measurement the same digital hardware may be used for many different types of measurement. One of these programs is described below. Others, for performing FFTs or displaying digital audio signals in oscilloscope fashion are also available.

In a conventional analogue signal generator and audio analyser test scheme one or more signal sources are summed to create the test signal. For harmonic or intermodulation distortion tests these are very low distortion sinewave oscillators; for other tests one of these may be a random noise generator or squarewave generator. After summation these signals are attenuated to the desired level and sent through a balancing amplifier or transformer to the device under test input.

The signal received from the device under test is buffered and converted to a ground-referenced signal for processing by the measurement hardware. The signal at this point is used by many different measurement circuits; an rms level meter, frequency counter, noise weighting filter and notch filter. The rms level meter provides the fundamental level reference for distortion measurements or may be used for general purpose level and amplitude response measurements. If THD+N is being measured the notch filter removes the fundamental.

The remaining signal is amplified and drives high-pass and low-pass band-limiting filters. This filtered signal goes to a second level meter for display of the distortion component amplitudes. A frequency counter will typically determine the incoming frequency. The measured value tunes the notch filter frequency and informs the operator as to the signal being measured. When noise measurements are needed a weighting filter and special ac to dc converter is used to simulate the frequency response of the human ear and correlate the measured value with the audible nature of the noise.

In the digital signal generator and analyser architecture, there is a strong similarity to the analogue implementation. Again, one or more signal sources are summed to create the test signal. Many digital signal generators have been developed in the past which simply read a sinewave or other test signal out of rom. This limits the resolution of the test signal to submultiples of the sampling frequency, inversely proportional to the rom address size. A 64K-word rom would be needed to obtain resolution of better than 1Hz. This integer frequency relationship also limits the number of different addresses read from rom, limiting the number of different codes tested in the DAC under test.

The DSP-1 computes the values of the output signal from equations and coefficients are stored in the program. This allows any sinewave to be generated with 24-bit resolution and accuracy in both frequency and amplitude. The waveforms are free from rom-size limitations and suffer no degradation in accuracy when set to non-integer frequency values. These signals are correctly dithered before being quantized to the desired output resolution, preventing erroneous results at low signal levels.

The analysis portion of the DSP measurement system is less complicated than the corresponding part of the analogue measurement system. The signal is processed by an rms level measurement routine, a frequency counter routine and a filter routine. Instead of having a bank of filters that are switched in and out there is one multistage filter – a ten-pole design composed of five second-order stages in cascade. The coefficients are programmed approp-

MEASUREMENTS ON COMMERCIAL CONVERTERS

For an alias rejection test an oversampling A/D converter, the ADC is driven with a sine wave and the output is measured digitally with the DSP-1 operating as a digital RMS meter (see diagram). The sinewave amplitude is set at 6dB below full scale to prevent overdriving the input filters of the converter. The sinewave frequency is swept from 10 to 200kHz and the RMS level of the digital signal shown. This provides a plot of the response of the converter to in-band and out-of-band signals. The alias products that the converter lets through show quite clearly in the graph at about 50dB below full scale or 44dB below the input, and are mirrored around 96 and 192kHz.

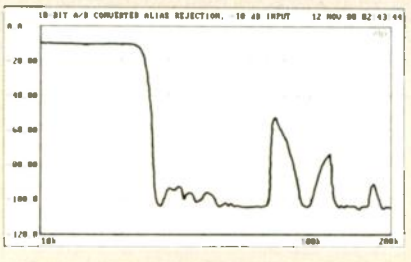
Level linearity on DA converters may be measured by generating a digital sinewave using the DSP. The output of the converter under test is measured with an analogue bandpass filter followed by an rms meter. Sweeping the amplitude of the digital signal and graphing the measured amplitude results in the plot shown above. Subtracting the best fit straight line from the data and re-graphing gives the deviation from linearity plot – within 1dB down to 95dB.

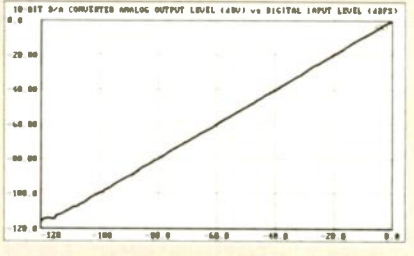
Inverting the functions of the analogue and digital portions of the measurement equipment allows linearity measurements on AD converters. The low distortion analogue generator stimulates the AD with a sinewave. The DSP is programmed to filter the digital signal from the converter with a passband centred at 997Hz and to compute the rms amplitude of the filter output. The amplitude of the analogue sinewave is swept and the digital rms level recorded. Converter is an oversampling 18 bit design with exceptional low-level linearity performance.

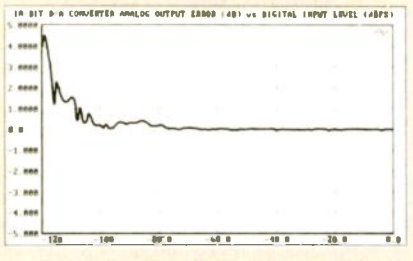
Using the DSP to generate a properly dithered low distortion digital sinewave, THD+N measurements may be performed on the DA converter measured earlier. The analogue distortion analyser measures and tracks the frequency out of the DA and tunes its notch filter appropriately. By sweeping the frequency or amplitude of the digital sinewave plots of the converter distortion may be obtained.

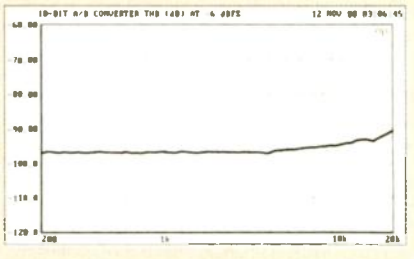
The digital and analogue functions of the system may again be interchanged to obtain measurements of an AD converter. The DSP measures the frequency and rms amplitude of the received data.

It computes the necessary coefficients to form a notch filter centered on the incoming sinewave. The filter output is measured with a second rms computation. A typical THD+N vs frequency plot of a professional audio grade converter is shown.





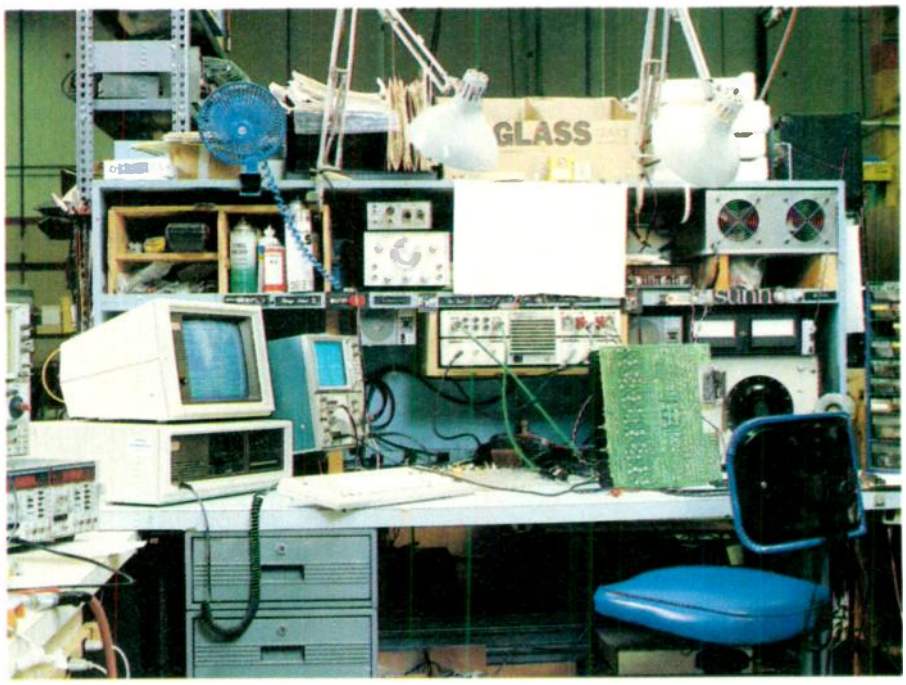




riately for any of the measurements to be made. When measuring THD+N this is programmed as an eight-pole notch filter. Two additional poles are used as a high pass filter to block incoming direct current. The notch filter is then tuned by the frequency counter that measures the input frequency.

There is an additional routine which computes the necessary coefficients of the digital filter for the measurements being made. When performing THD+N measurements the frequency value is used to derive the 20 coefficients required for the four sections of filter. The five coefficients to program the two poles of highpass are set by the desired high-pass frequency. For noise measurements the filter is converted to a weighting filter by re-programming these coefficients with the appropriate values.

The process has 250 instructions available between samples at a 48kHz sampling rate. The real-time tasks are allocated 200 of these instructions and operate in a loop. The remaining 50 instructions are allocated to background tasks which run in a separate loop. The signal generation, scaling, and dither must all be done in real time. On the measurement side, the rms computation of the input signal, filtering, amplitude detection of the filtered signal and zero crossing detection for the frequency counter must also be done in real time. Frequency computation, coefficient computation, coefficient loading, housekeeping tasks and communication with the PC happen in the background.



By Dr Richard Cabot, vice-president and principal engineer with Audio Precision Inc. of Beaverton, Oregon. The company was formed in 1984 by former Tektronix engineers specializing in high-tech audio test equipment, and is represented in the UK by Scenic Sounds of London, telephone 01-387 1262

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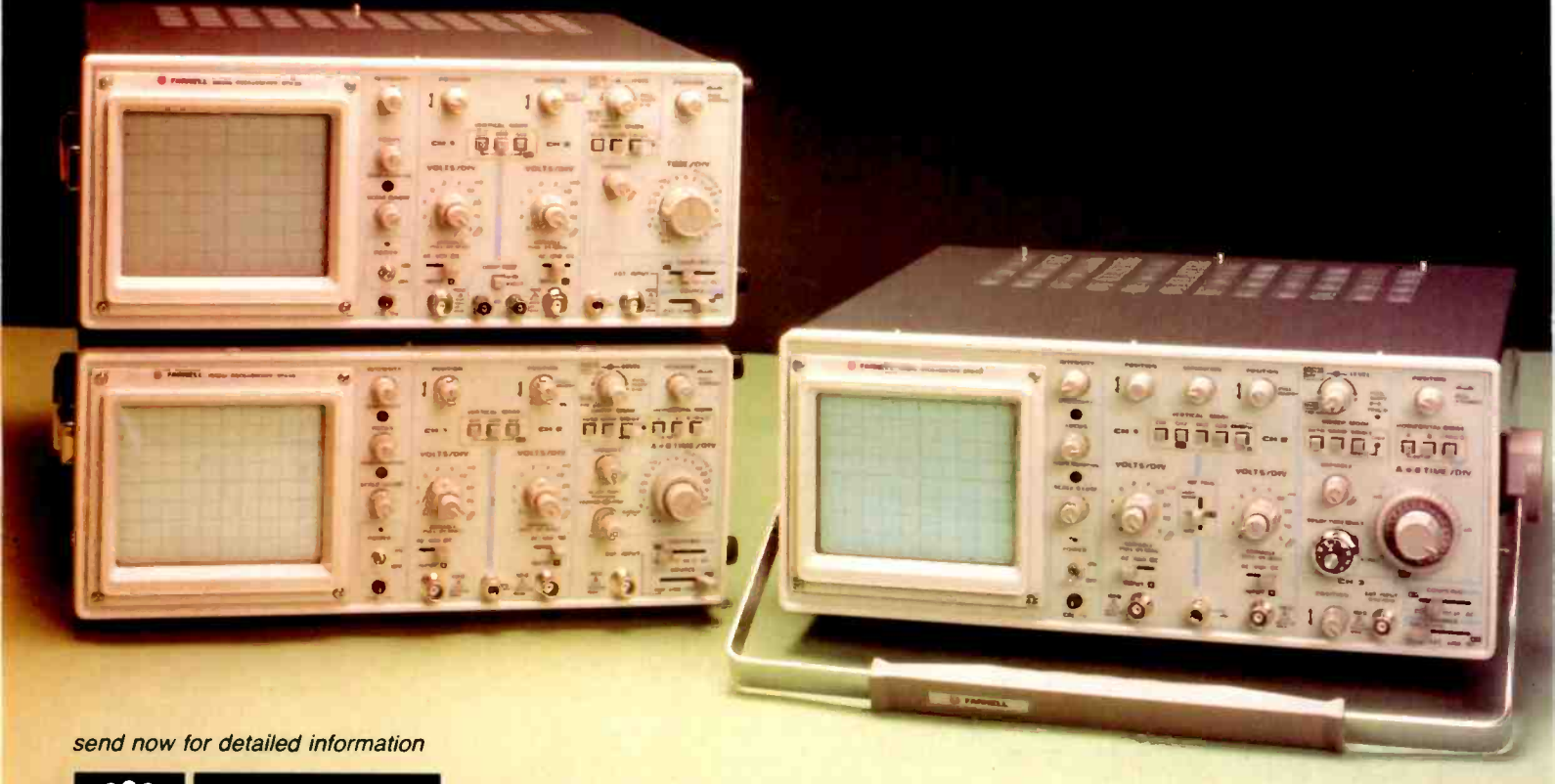

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TEST STRUCTURES IN WAFER FABRICATION

Andrew Walton, of the Edinburgh Microfabrication Facility, highlights the topical issues in wafer process control

When integrated circuits are fabricated the manufacturing process is first parametrically checked before any of the chips are functionally tested. This monitors the engineering parameters, while the functional testing which follows provides information on the yield of the process. Parametric testing provides the process engineer with the first confirmation that each of the process steps has performed within specification and the decision can then be made about whether the wafers should proceed to functional test.

The measurement of test structures provides an insight into the fabrication process which would not otherwise be available. Not only does it give information about device performance but also supplies additional data on individual process step. This gives the process engineer the ability to not only identify the exact process step that caused a problem but also to monitor the uniformity of processing across wafers and batches.

Parametric testing is performed on devices and test structures which have been designed to measure specific parameters. These structures are located either on a process control chip which is dropped into the wafer at a few sites or in the scribe channel. The smaller-geometry processes which expose each chip individually tend to locate the test structures in the scribe channel.

The dilemma for the manufacturer is the decision on how much area should be devoted to test structures at the expense of product chips. If too much area is used for test structures profitability is reduced. On the other hand, too few test structures is potentially dangerous, since the performance of the process cannot be properly monitored and drifts in device parameters may not be detected except by catastrophic failures at functional test. If this is the case there is then the further problem that the specialist test structures will not be available for use in a diagnostic mode. There is no straightforward answer to this issue of area ratios, and while the experience gained from present day technologies may be transferred to technically more advanced processes there is no guarantee that this approach will be successful.

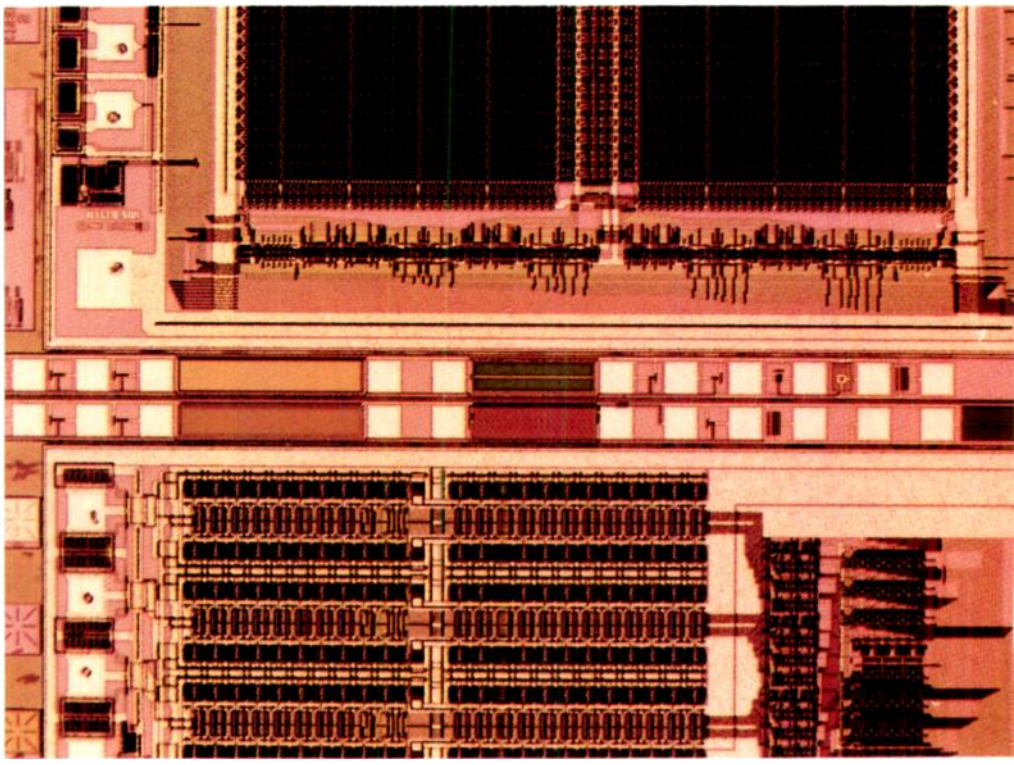
There is much discussion throughout the semiconductor industry trying to determine the minimum number of structures required to fully characterize a process. This problem is also related to the problem of data storage and collection. A fabrication line that starts 5,000 wafers each week with every one requiring 100 measurements on all 100 sites produces 10^7 items of data per week. This is in addition to the measurements that are made during the process and consequently data reduction techniques must be employed.

Future tendencies

Parametric testing is an important part of integrated circuit process control. As manufacturing systems develop, all the information relating to wafers is now being stored on the same database. This includes in-process measurements, facilities information, parametric and functional test together with the processing history of each wafer. This makes the efficient use of the information much simpler giving engineers the option of posing questions which examine what batches of wafers have in common when their parameter spread is outside specification. Perhaps more importantly they can also ask the same question about the batches that have a very low spread in parameter values to help in the identification of the procedures which give the best control of the process. This type of analysis requires a high degree of skill and work is now being undertaken to develop expert systems to help diagnose processing problems and devise measurement strategies to automate operations.

The IEEE International Conference on Microelectronic Test Structures is the main forum where issues are debated and the latest developments in test structure design and measurement methodology reported. The second conference with this title, organised by Dr Walton, was held in Edinburgh, March 13, 14.

Wafer test structures can be dropped into a scribe channel, as in this Inmos wafer (centre).



HOW PARAMETERS ARE MEASURED

Sheet resistance. The Greek Cross shown is used for measuring the sheet resistance of conducting layers. The measurement is simple with current being forced between pads 1 and 2 and voltage measured between pads 3 and 4. The sheet resistance is then calculated using

$$R_s = 4.53\frac{V_{34}}{I_{12}}\Omega/\square.$$

The calculation has no dimensions involved and consequently does not depend on the accurate control of dimensions.

Linewidth. The structure shown below can be used for electrically measuring the linewidth of conducting tracks. On the left hand side is a Greek cross from which the sheet resistance is derived. Curent is then forced along the main track between pads 1 and 2 and the voltage measured between pads 3 and 4. Linewidth is then calculated from

$$W = R_s L\frac{I_{12}}{V_{34}}.$$

Misalignment. A structure that can be used to measure the degree of misalignment between two layers consists of a conducting track with tapes for voltage measurements spaced at equal distances. One of these taps is a contact and provided that it is perfectly aligned, the voltages measured between adjacent taps will be equal. But if the contact is misaligned the voltages will be unequal and the value of misalignment

$$c = \left[\frac{(V_1 - V_2) - (V_2 - V_3)}{(V_4 - V_3)}\right]S.$$

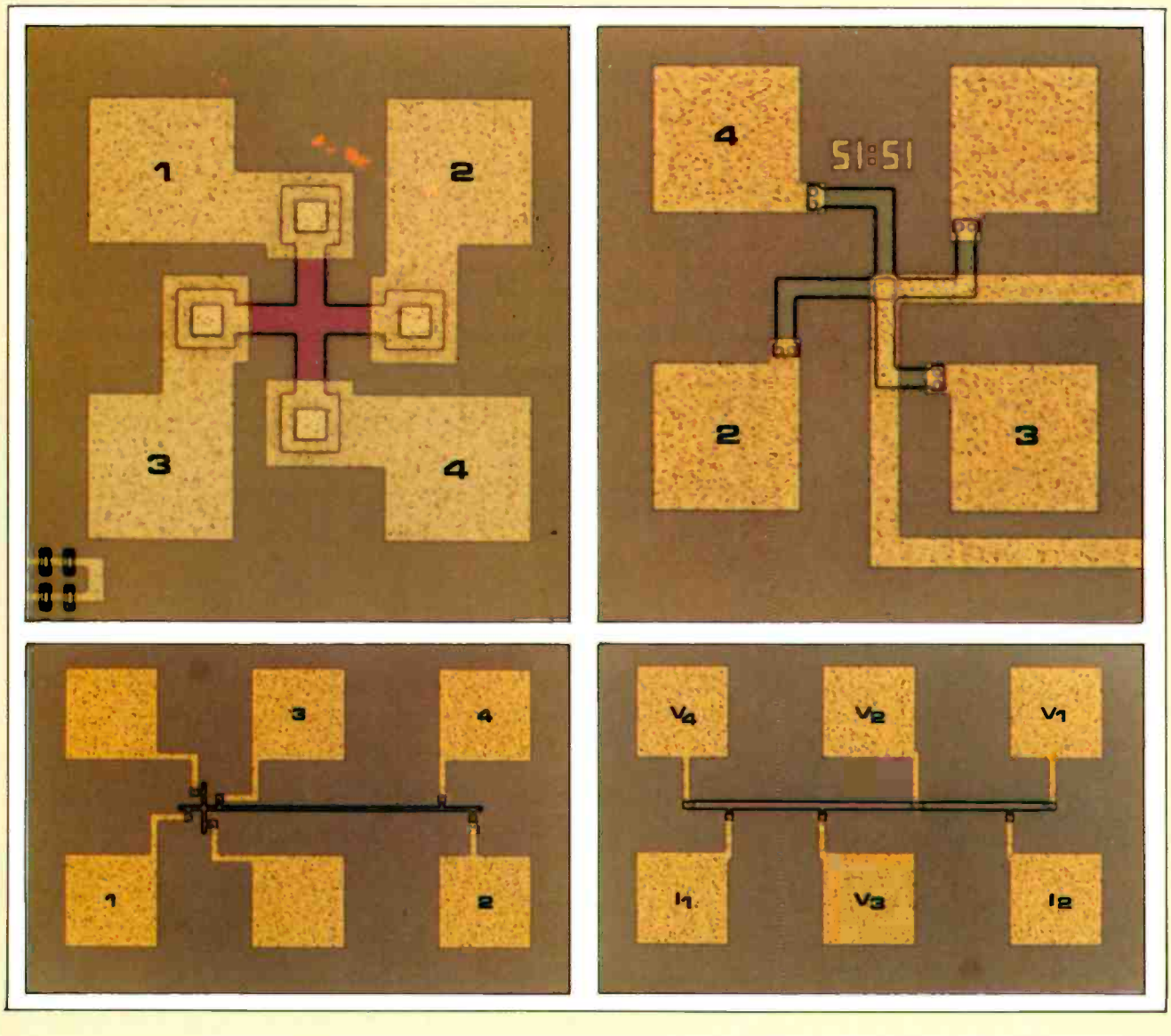
This structure only gives misalignment along one axis and an identical one at 90° is required to obtain the full misalignment vector.

Contact resistance. To monitor contact resistance between two conducting layers current is forced between pads 1 and 2 and voltage sensed between pads 3 and 4. The interfacial contact resistance is simply

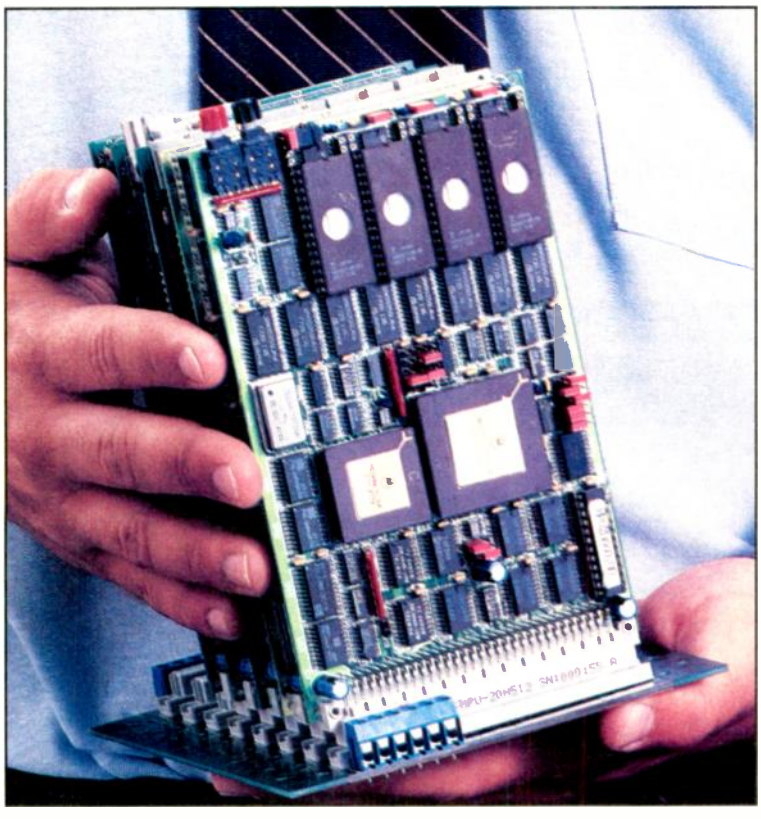
$$R_c = \frac{V_{34}}{I_{12}}\Omega.$$

Data display. Further aids are wafer maps which show the variation of different parameters over a wafer. A vector map shows misalignment across a wafer while a shaded map gives the variation of transistor threshold voltage. Information displayed in these formats is of great value to the process engineer.

The Greek Cross measures resistivity by forcing current through two adjacent pads and measuring voltage between the other two – top left. This enables linewidth to be determined from the ratio of current along the main track to the voltage drop across the two right-most upper pads (bottom left photo). Bottom right structure tests for misalignment between layers along one axis and an identical one at 90° is required. Kelvin structure, top right, measures contact resistance between conducting layers.



Stop, Look, Compare and Make The Right Choice



	G-64	Single VME	Double VME
Data bus	32-bit	16-bit	32-bit
Address bus	32 Mbytes	16 Mbytes	4 Gbytes
Bandwidth	40 Mbytes/s	20 Mbytes/s	40 Mbytes/s
Memory transfers	Async	Async	Async
I/O transfers	Sync & Async	Async Only	Async Only
Address modifiers	2	6	6
Min. address lines	10	16	16
Min. data width	8-bit	8-bit	8-bit
Interrupt levels	6	7	7
Vectored Interrupts	Yes	Yes	Yes
Autovectors	Yes	No	No
Multiprocessor	Yes	Yes	Yes
Arbitration type	Parallel	Daisy Chain	Daisy Chain
Priority levels	31	4	4
Typ. arbitration time	200 ns	1.4µs	1.4 µs
Max. arbitration time	220 ns	3µs	3µs
Position dependent	No	Yes	Yes
DMA	Yes	Yes	Yes
Message passing	Yes	No	No
Eurocard	Yes	Yes	Yes
Connector	96 Pin DIN	96 Pin DIN	2 x 96 Pin DIN
Bard Dimension (mm)	100 x 160	100 x 160	233 x 160
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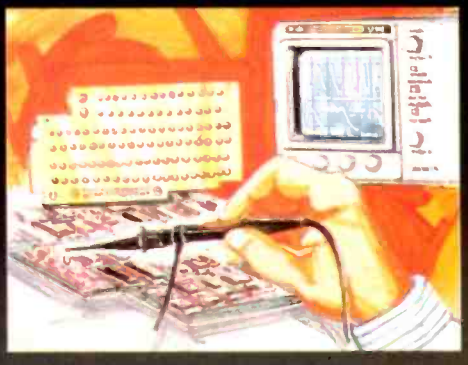

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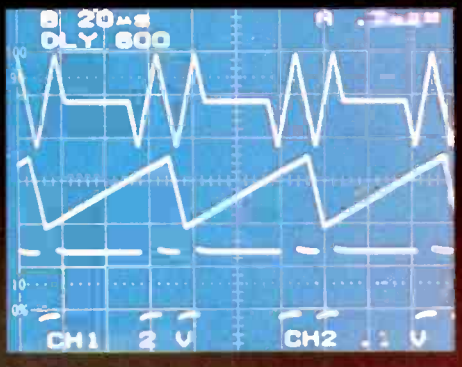

Digital display: Main parameters displayed on CRT.

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WAFER-SCALE KERNEL TESTING

Can we make faulty circuitry work properly by pouring in more and more circuitry? Improved reliability suggests that Catt's Spiral Algorithm may be superfluous

The conventional way of getting integrated circuits made and installed into a computer system is tortuous, expensive, and damages some of the circuits involved. It increases the size and weight of the resulting system far beyond that of the tiny active chips that it contains.

A nearly perfect product, a processed semiconductor wafer with 300 identical circuits each containing some one million interconnected components is manufactured at a cost of 500 pounds. It is then subjected to a testing procedure where it is established which of the 300 circuits are perfectly sound – some 50% of them – and which are faulty. This information is recorded, and the wafer broken up (diced) into 300 chips, which are sorted into good and bad. Each of the good chips is then assembled into a package with leads coming out of it and again tested to see if something went wrong during assembly. The chips that are still good, having survived the assembly into packages, are then delivered to another manufacturer who plugs them into printed circuit boards and solders them in. The boards are then tested and the good boards retained and assembled into a complete computer system.

There are many hidden costs in this process of repeated testing, rewiring, testing, rewiring. Some area on an integrated circuit is taken up by the pads which are first used by the expensive tester as it moves across the wafer to probe each chip and test it, and which are then used as sites for wire bonding. Failure of the probe tester to make good contact to a pad will lead to a good chip being adjudged faulty, and rejected. Faults will be introduced during the wire bonding process. Printed circuits boards can be faulty, and in any case they are expensive and bulky. The edge connector introduces expense and also faults, especially later on, due to corrosion of contacts.

This tortuous procedure is a technique for checking out the performance of each segment ('chip') of the semiconductor wafer and recording the test results in the form of hard wiring between the good circuits. It adheres to ancient procedures, going back to the manufacture and use of thermionic valve (and earlier) computers, and makes no concessions to the peculiarities of semiconduc-

Turn to page 406

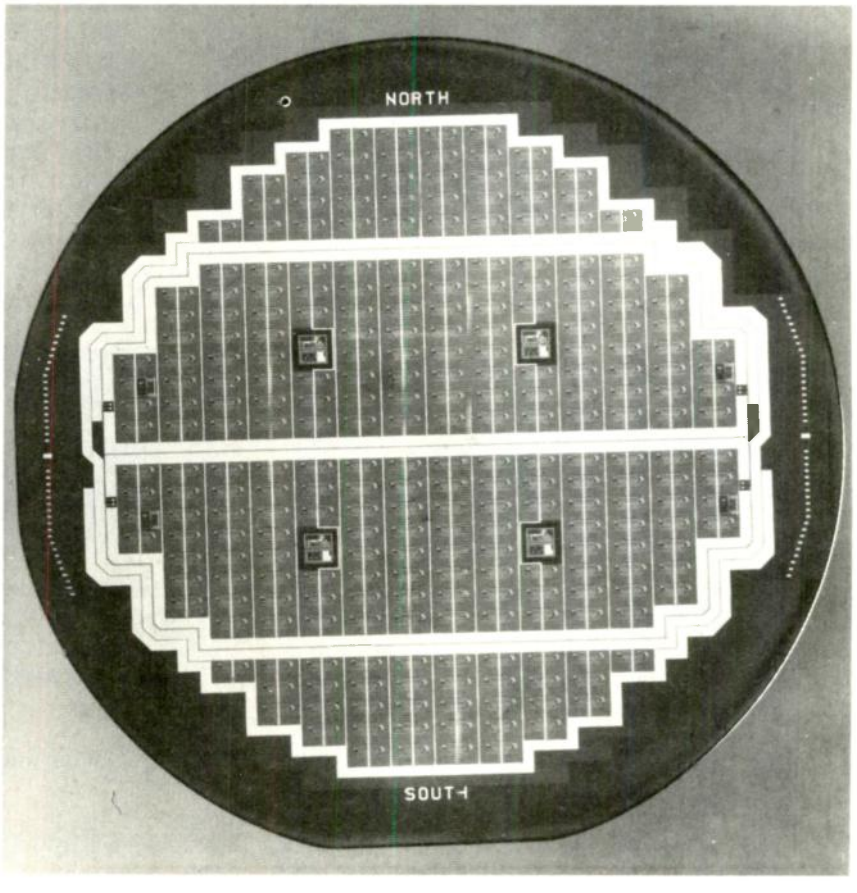
A QUARTER CENTURY OF WAFER INTEGRATION

One of the first things that Ivor Catt did when he left the computer industry and joined Motorola Semiconductor Products in Phoenix, Arizona, in 1964 was to propose wafer-scale integration. He still has a copy of the memo he sent to Walt Seelbach, then deputy head of R&D for integrated circuits, who said he was amused by it. Much to Catt's frustration it was regarded as a spoof. One of its problems, besides getting industry interested in the first place, was how to distinguish between good and bad 'chips' on the wafer and how to connect up only the good ones.

The solution to this had to wait until 1972, when Catt patented the Spiral Algorithm. This later gained reluctant support from the NRDC and ACTP, a section of the DTI, who funded projects at Middlesex Polytechnic, Brunel University and RSRE Malvern. The guiding principle in all these projects seemed, according to Catt, to be that Catt himself should be kept at arms length!

In the early 1980's Burroughs, Cumbernauld, built working wafers using the spiral algorithm – see photograph – but the project was frozen by new top management imported from IBM. In the mid 80's, Catt brought the Burroughs team to Sir Clive Sinclair, at Milton Hall, Cambridge. Working 0.5 Mbyte wafers were produced in time for the biggest slump ever in the ram market.

This year, 20 Mbyte wafers will be produced by the company, renamed Anamartic, which is half owned and largely funded by Fujitsu, a major chip manufacturer, and Tandem, a major manufacturer of fault-tolerant computers. Total funding so far is of the order of ten million pounds. The wafers are being manufactured by Fujitsu, whose engineers assisted in the presentation of the new wafer to last month's IEEE Solid-State Circuits Conference in New York.



Oasis Instruments

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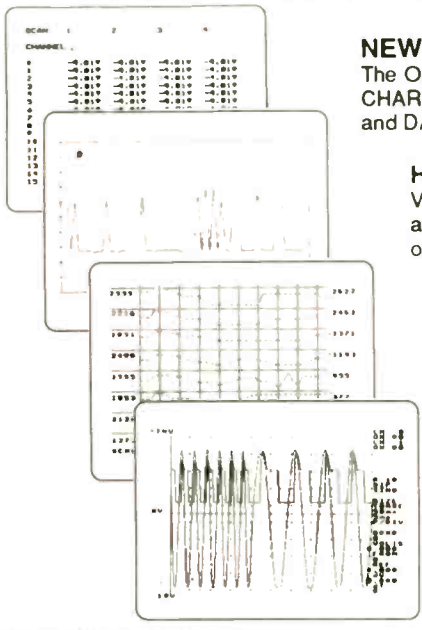

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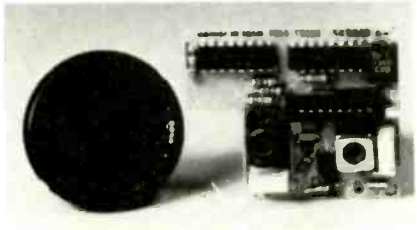

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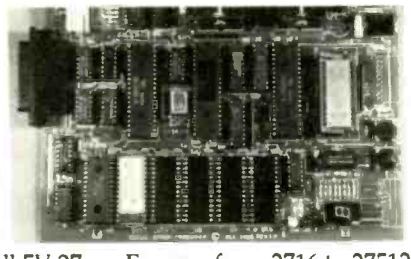

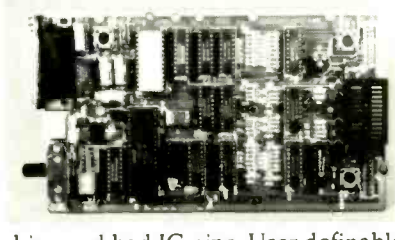

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AFTER MODULARITY AND AUTOMATION, WHAT NEXT?

For some time, co-ordinating the timing signals of instruments in a test station has been a hidden problem. While the issues of modularity and automation have been successfully addressed system-level timing has suffered from the lack of hardware timing architectures, and as a result timing control has been largely relegated to software. Previous architectures, such as the IEEE 488 bus and IBM PC-based plug-in card systems, have contained few provisions for system timing. Newer architectures, however, such as the VXI bus and RTSI bus, provide mechanisms for precise hardware system-level timing. But there is still a need for a software specification that deals with system timing issues in a top-down fashion.

The demands placed on a hardware timing architecture are rigorous; it must allow the system timing to be reconfigured dynamically and centrally controlled, provide a mechanism for routing timing signals between test devices, and provide mechanisms for synchronizing devices and controlling timing sequences. Another requirement is a highly accurate timebase or clock that acts as a source for device timing signals.

Though newer architectures – VXIbus and RTSIbus – provide for precise system-level timing, there is still a need for a software spec that deals with timing issues in a top-down way.

The timing characteristics of the signal routing mechanism must be carefully controlled to minimize skew and propagation-delay effects on the system timing precision. A system-level timing architecture that provides flexible reconfiguration and well-understood timing characteristics can improve both the synchronization accuracy and throughput of the test and measurement system.

Three of the mechanisms that have been used to deal with system timing measurement problems are the IEEE488 bus, point-to-point cabling of timing signals, and PC-based systems with plug-in instrumentation cards. Initially, instrumentation-based ATE consisted of large custom systems with internal hardwired timing. These systems, however, brought with them considerable drawbacks, including a lack of flexibility and standards, and adverse timing effects due to ad-hoc configuration and cable lengths.

The advent of the 488 standard provided a modular standard for automatic system control. Though it includes mechanisms for remotely programming and controlling devices and obtaining data from devices, with some provisions for system timing, the GPIB does not really address precision timing and synchronization needs, nor the need to route triggers, clocks, and other timing signals between the modular devices.

The bus provides a general-purpose trigger mechanism with devices addressed and sent the group execute trigger command, which allows multiple devices to be triggered simultaneously by the bus controller. Devices can also be selectively triggered at different times. But triggering in this type of system is causal, with the timing precision

IT'S ABOUT TIME

Within the test process of system configuration, stimulus application, and response measurement, the timing requirements include controlling a sequence of events, starting and stopping measurements, co-ordinating stimulus and response activities, and synchronizing measurements between two or more instruments. During system configuration, signal sources and acquisition instruments are connected to the device under test, and the instruments must then be reset. Before a stimulus can be applied the test system has to settle, switches must be closed and signals must reach a steady state.

The application of the stimuli dictate the co-ordination of response measurement timing; the occurrence of the response may be fixed and well known, or devices may need to be triggered by the response. The timing components to control this process include a master clock for centralised control (the resolution of which determines the degree of synchronization precision), and a number of clocks derived from the master clock to acquire and generate signals. If all signal generation and acquisition clocks are derived from the same master clock, synchronous and simultaneous sampling can be used to enhance the test process.

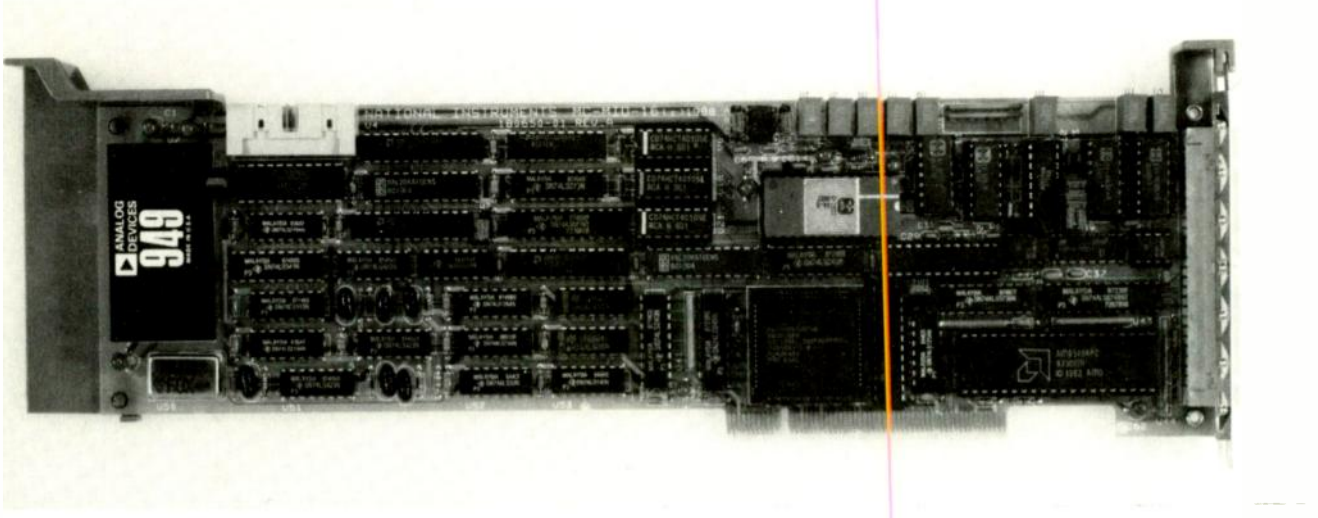
Within the system timing scheme, there are other concerns, namely repetition periods, triggering and gating, and delays. Repetition periods may appear at several levels, determining the execution rate for each measurement step or the rate at which the entire process is repeated. In addition, instruments must be or triggered to take measurements or generate signals during a given time interval. Gates and triggers are used to synchronize signal generation and acquisition between multiple instruments. Delays allow devices to respond to the same triggers, performing their functions at programmable time intervals after the trigger is received – important in controlling the time between stimulus application and response measurement.

Synchronization between devices is critical for even the simplest automated test. For example, the process of powering up a power supply and taking voltmeter readings on to measure gain and current of an amplifier carries with it a number of timing requirements: waiting for the system to settle after power up, switching different points of the amplifier to the voltmeter input, waiting for the voltmeter to settle each time, and triggering the voltmeter for each reading.

Timing requirements for waveform capturing are even more complex. Pulse measurements in the time domain require precise quantification of propagation delays; rising edges must be captured and quantified for frequency domain measurements such as spectrum analysis and distortion.

Another class of timing requirements involves the sequencing and synchronization of multiple instruments to perform a test. This class of measurement requires an emphasis on triggering, delays, routing of timing signals, and switching instruments. Multiple instrument measurements also frequently require settling time before invoking stimuli or collecting data.

Combinations of linear and digital instruments form another class of test that cannot be performed without centralized timing. In many systems, both analogue and digital signals must be generated and measured concurrently, and frequently one instrument can't do the whole job. In this situation, linear and digital instruments must be triggered together, and in some cases, it may be necessary for all devices to run off of the same sampling clocks or timebase.



limited by both the slowest device in the system (due to asynchronous handshaking protocol) and the speed with which the controller can issue commands. In addition, system timing is not referenced to a clock, making timing control highly system-dependent and best relegated to systems that require millisecond-level precision.

Another drawback of message-based GPIB systems is the fact no provision exists for controlled timing sequences. If the get command to a device must be delayed, the device must generate the delay itself. This is particularly true in stimulus and response tests and many instruments are incapable of generating their own delays. The alternative is to individually trigger each instrument over the bus, but this degrades the precision of the timing control sequence. Many systems attempt to solve the timing precision problem by discretely hooking timing signals and triggers between instruments. This ad hoc approach meets the timing constraints, but each hookup is a custom job and can't be reconfigured via programming. In addition, cable lengths have an impact on timing accuracy in discrete hookup systems. Since signal propagation time is around 5 ns/m, cable lengths must be carefully matched for high timing precision.

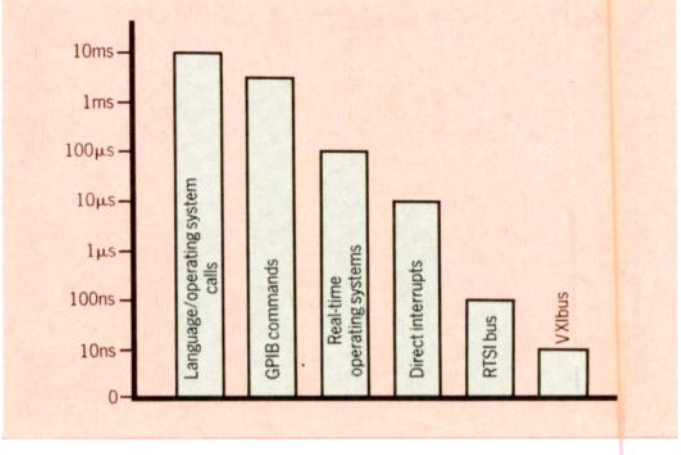
While test and measurement systems constructed from PC-based plug-in instrumentation cards tend to be more primitive at the system level, because of this timing can usually be controlled much more tightly. In theory the precision for the processor in controlling individual boards is tied to the speed of the bus cycles, making microsecond resolution possible. Plug-in boards typically have some on-board timing capabilities, and some have external timing controlled. Other plug-in systems support several modules on one board, and some limited timing (usually a fixed configuration) can be shared between modules. But multiple plug-in boards must often work together to make measurements, and system configuration must be flexible.

In PC-based test and measurement systems, system-level timing is definitely an afterthought. PC buses are designed to send data between boards, and while the bus may have a clock, there is no provision for sending timing signals from the processor to cards. To send hardware signals between cards, both external timing signals and an external hookup is required. For these systems, the processor controls system-level timing. And while processors can now execute i/o instructions within a few hundred nanoseconds, the timing accuracy of the hardware bus in a PC isn't even close to the capability of the processor.

In addition, the PC processor is dedicated to running the operating system and managing screen, disk and user interface activity, not controlling system timing. And in a PC, the efficiency of the operating system determines the precision of system timing. Once system timing is controlled via software there is no access to the bus clock, only access to the system clock, which limits timing precision to hundredths of seconds. While some system software languages support extended instruction sets for instrumentation that include timing instructions the resolution of these instructions is limited to system clock resolution of ten milliseconds.

Some user invest in real-time operating systems, but the interrupt latency and context switching required by these systems limit the timing precision of this solution to hundredths of microseconds. Since there is no standard real-time operating system on the IBM PC, users typically develop interrupt-driven applications written in assembly language to meet their timing requirements. Bypassing the operating system and using dedicated interrupts may improve the performance to a few tens of microseconds.

Achievable timing precision depends on how the timing is implemented. Hardware architectures that include timing allow much higher timing precision than software. This figure gives a general view of the performance of different implementations.



VXIbus timing precision

Current architectures emphasize system modularity and data and control connectivity, with no hardware system timing provisions. This relegates timing to software, with timing precision limited to just over 1ms for general software. But new instrumentation architectures such as the VXIbus implement stringent specifications that allow system synchronization to within 10 ns, and inter-module synchronization to within 2ns.

The VXI bus timing architecture allows high-precision timing co-ordination of instrument modules, and offers a timing interconnection system that can be easily reconfigured. One of the most useful contributions of the VXI bus standard is

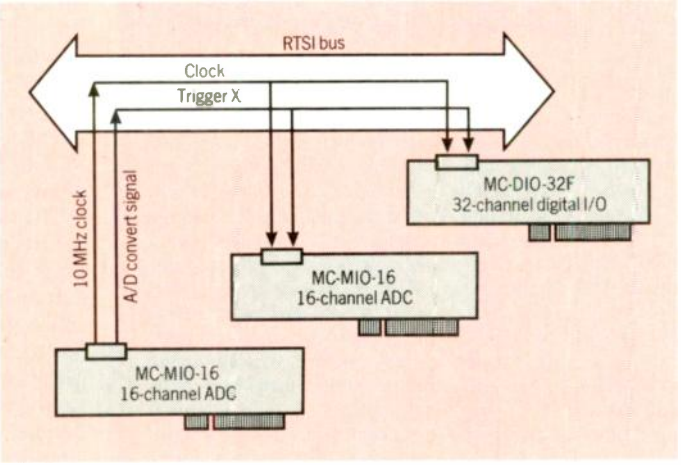
the definition of a backplane architecture that allows timing signals to be routed between modules and timing precision. The VXI bus timing architecture includes a 10MHz timing system and a 100MHz timing system and modules can support either or both. The 100MHz clock is synchronized with the 10MHz clock, and protocols for synchronizing modules using either system are defined.

The 10MHz timing system consists of system clock and eight t.t.l. trigger lines. The source of the clock is the Slot-0 card, and the clock is buffered in the VXI backplane and distributed separately to each module. The clock accuracy must be within at least 0.01% of 10MHz. The t.t.l. trigger lines are open-collector and can be driven by any module, can carry triggers, clocks or data, or be used for handshaking between modules. Trigger connections can be programmed; for example, any device capable of sending or receiving a trigger can connect to any of the eight lines.

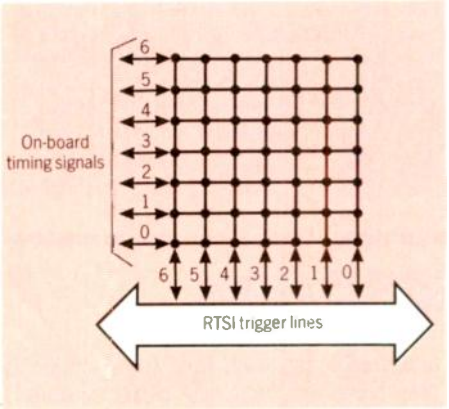
The 100MHz timing system consists of system clock, a clock-edge qualifier signal named sync100, and e.c.l. star bus and a trigger bus. The source of the clock and the sync100 signal is the Slot-0 card. Both signals are buffered and routed separately to each module, with matched distribution delays that limit the clock skew to a maximum of 2ns between any two modules. The clock accuracy must be within 1% of 100MHz ± 0.01%. The sync100 signal is used to synchronize multiple modules with respect to a given 100MHz clock rising edge.

Several protocols that specify timing requirements are defined for using the trigger lines. These protocols can broadcast triggers to modules, provide handshaking between modules for co-ordination the start and completion of activities, send clocks and data, and synchronize multiple module clusters. For synchronizing multiple modules, a start/stop protocol is defined that requires the slot-0 module to drive a t.t.l. trigger line synchronously with the 10MHz clock. In this protocol, an asserted state signifies 'start' and a generated state signifies 'stop'. Participating modules respond to this signal at the next 10MHz clock rising edge.

Other sources of timing precision in the VXI bus include the e.c.l. star bus and trigger bus. Star bus consists of two bidirectional lines (starX and starY) that are sent separately to each module from the slot-0 module. Any module can route a timing signal to the slot-0 module via on of the star trigger lines, and can then selectively route the signal onto the star lines of any other module using a crossbar switch. The backplane allows a maximum timing skew of 2ns between any two star signals, and a maximum delay of 5ns between the slot-0 module and other modules. The trigger bus consists of six parallel e.c.l. trigger lines, with protocols similar to the t.t.l. lines. An extension to the protocols allows the lines to be synchronized with modules using the 10MHz timing system.



The RTSI bus makes it possible for two or more data acquisition boards to sample incoming analogue and digital data simultaneously by using the same clocks.



In the RTSI switch data acquisition boards are connected to the bus trigger lines through a 7×7 bidirectional crossbar switch that is completely software programmable. This general approach make system configuration and reconfiguration very easy.

The RTSI bus

The RTSI*bus, National Instruments' timing architecture, facilitates interconnection of timing signals between boards plugged into PC backplanes. This architecture compensates for the lack of timing signal interconnection in conventional PC buses with the bus implemented on instrumentation boards for NuBus, MicroChannel and PC/AT bus. The RTSI bus allows the timing synchronization of several plug-in instrumentation boards, with the boards interconnected via a cable run across the top of the boards.

*Real-Time System Interface.

The timing section of the RTSI bus consists of a 10MHz clock and seven general-purpose t.t.l. trigger lines that can send any t.t.l. signal from one board to any other board. Each board is equipped with a crossbar switch that allows various signals from each board to be connected to any one of the seven trigger lines under software control. Because of the close proximity of the PC plug-in boards, the length of the timing signal is minimized, with propagation delays from the input of the crossbar switch on the sending board to the output of the crossbar switch on the receiving board around 50ns.

A common timebase of 10MHz is provided for all boards. In some systems, such as the NuBus, this clock is part of the computer bus; on others, the clock is sent across the RTSI bus. This clock allows multiple boards to operate off a common timebase. Since three trigger and timing procols on the RTSI bus are undefined, a variety of different protocols can be used. The bus also allows multiple boards to share timing signals in a programmable system.

The future is software

Both the VXI bus and the RTSI bus provide the centralized timing control that has been missing in previous hardware architectures. But timing control should also be spelled out in software, with a specification that makes the details of the buses and hardware transparent. System interconnection could be specified by an interconnection table for each experiment, or a sequence of required test interconnections. Similarly, a graphics-based timing mechanism for specifying signal connections between modules could be used. (Summation uses this type of software-programmable trigger bus in their VME bus-based modular system.) At the driver level, each board could have a list of signals that connect to the bus, with a simple call used for connection and disconnection (the RTSI bus uses this type of format). But the system software must be smart enough to automatically interconnect devices once the system timing is specified.

Ways to specify system timing include a timing diagram or by assigning time values to critical components of an execution diagram or program. Device synchronization, timing relationships between devices, timing sequences, repetition rates and delays also must be specified.

A top-down timing specification would be preferable to the current bottom-up method. The key issue in this argument is timing translation. With current software, users must translate between their timing diagram and the actual timing implementation specified in the hardware. An intuitive

SYNCHRONIZING THE INSTRUMENTS

Many current state-of-the-art test and measurement systems consist of rack-and-stack modular instrumentation in which each instrument is a specialized measurement or stimulus device with its own configuration, timing and synchronization needs. As integration and automation of these instruments has become more popular the ability to control the internal timing of these instruments has increased. These instruments include waveform digitizers, voltmeters, counters, logic analysers and waveform generators.

Digitizers capture waveforms both before and after trigger events, with the information they gather usually passed to some other device for processing. Timing parameters consist of sample rate, sample record length, trigger and delays. They offer both internal and external triggering options; in an ATE system, external triggering can be used to co-ordinate digitizer synchronization and signal acquisition with other devices. Digitizers also allow a programmable delay from trigger, which is useful for synchronizing the capture/measurement phase after test initiation. Digitizers can be programmed to acquire a specific number of samples at a set sampling rate, resulting in a "time window" for acquiring a waveform. In some systems, this sample rate can be externally controlled and synchronized with other devices. Controlling the sampling frequency allows the digitizer to sample synchronously with the device generating the signal. This eases the measurement process by guaranteeing that the digitizing will capture the peak of a waveform or capture an integer.

Counters are synchronized with stop and start triggers. Pulse and waveform generators provides the test stimuli, and must be co-ordinated with the data acquisition and time-measuring devices to perform a measurement. Some pulse and waveform generators allow the signal output update rate to be externally controlled, and triggering and gating of signal generation is also often possible. In addition, many of these devices generate timing signals that allow synchronization with other test devices.

Voltmeters are often allowed to run free, making it difficult to determine the precise instant during which the measurement will be made, or making it necessary to allow extra time in the measurement window for the instrument. The problem is solved by synchronizing the measurement to a voltmeter trigger. Both the sampling rate and the required settling time of the voltmeter must be taken into account.

method, in which users specify timing as a 'time window', may be preferable. For example, to generate a signal for a certain time duration and then sample a signal for another time duration and sampling frequency. This can in turn be translated into sampling frequency or period and number of points required to program the device.

The top-level software should intuitive in nature, performing all the necessary translations to program the devices, as well as automatic error checking of system timing constraints. Timing violations must be reported, and it makes sense to let hardware drivers be responsible for verifying that the timing requirements are met. Finally, some devices, such as data acquisition systems, typically have their own timing system and can be synchronized at a high level solely with the use of triggers. So any timing specification must take into account the self-timing capability of these types of devices and system timing hierarchies.

By James J. Truchard and Audrey F. Harvey, National Instruments, Austin, Texas. National Instruments UK office is at 34 Eden Street, Kingston-upon-Thames, tel 01-549 3444.

WAFER SCALE INTEGRATION

tor technology. Nearly all approaches to wafer scale integration, including that of Texas Instruments in the 1960's and Trilogy in the 1980's, conformed rigidly to this manufacturing/testing sequence, which has remained unaltered in computer systems from the 1950's. All such approaches to wafer-scale integration have been unsuccessful.

Self-organising, fault-tolerant w.s.i.

The only proven successful approach to wafer-scale integration, the spiral algorithm (*Wireless World*, July 1981), breaks away from this tradition. Kernel Logic (*EWW* March 1989) also breaks with tradition. Two points arise;

- There is a more reliable way to interconnect good circuits on the wafer; one that does not increase the cost of the final product so dramatically.
- It is not necessary to hard-wire in the information as to which circuits are good and which are bad. Notice that if we do, then the failure of a single component in service leads to the need for manual intervention to repair the system.

In the successful approach to wafer-scale integration, the good circuits are connected electronically (logically) rather than by hard wiring. These soft connections are volatile, and are broken each time the machine is powered down, and a new, perfect system is built, using spare circuits on the wafer. This repairing process is automatic, and does not require human intervention.

In the 1972 spiral algorithm, all the testing procedures are off-wafer. Test routines are fed into the wafer at one point only, and routed to the chip currently under test through other, perfect, chips. In the 1988 kernel algorithm, a tiny portion of each chip is assumed to be perfect and dedicated to testing.

The Fubini Syndrome

In the 1960's, in a lecture in Phoenix Arizona, Fubini stated what he called 'The American Syndrome'. Whereas in the past, technical limitations prevented the USA from doing many things, a watershed had now been passed, and the USA had become all-powerful, with the technical capability to do anything. The American Syndrome was that the Americans always said, "Since we can do it, we will do it." With the realisation that now anything could be done, a new approach was needed. It was now important to decide which mountains we really wanted to have moved into which new positions, rather than just to move them all, all of the time.

A revolution of the same magnitude is happening in the field of system testing. The Spiral/Kernel experience in wafer scale integration points the way to what might be coming more generally in the future. In the case of spiral, extra configuration logic, dedicated to machine repair, is included in each chip at no extra cost. In the later case of Kernel, a segment of each chip is dedicated to testing the chip, again at no extra cost. This segment is itself unreliable, but in the move from Spiral to Kernel, its reliability improves.

The 1972 spiral algorithm was prompted by the appearance of chips of reasonable yield with 10,000 components. The 1988 kernel algorithm was prompted by the appearance of chips of reasonable yield with 1,000,000 components. It is difficult to think in terms of a chip with 1,000,000,000 components and the kind of algorithm that would be appropriate at that time.

Try to picture a future time when we will be able to add unlimited circuitry at no significant cost, this circuitry being dedicated to diagnosis and repair. The fact that the amount of circuitry is unlimited will modify the idea that it is faulty. Can we make faulty circuitry function properly by pouring in more and more circuitry? The answer is unclear, and difficult to think about, because we do not normally think in terms of unlimited hardware. The kernel algorithm indicates that perhaps we can make circuitry self repairing.

By Ivor Catt, Kernel Consultants, PO Box 99, St Albans.

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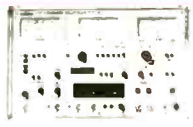

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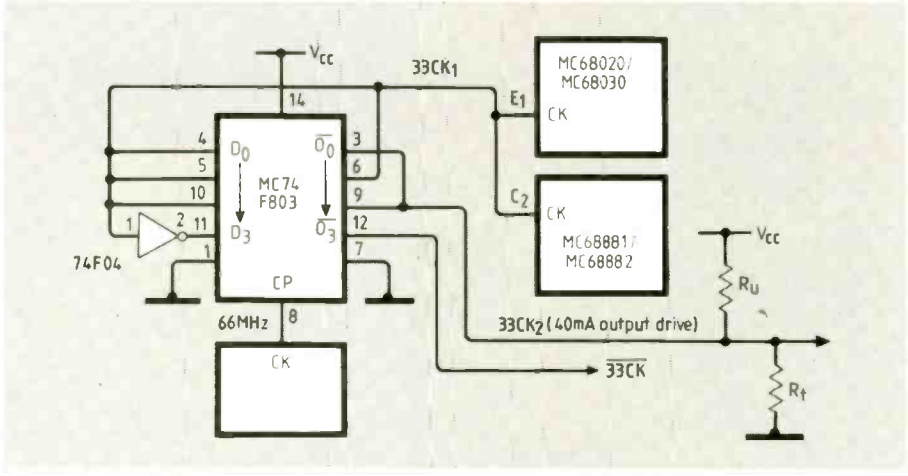
APPLICATIONS SUMMARY

Clock driving

Closely matched outputs of the MC74F803 provide an ideal interface for the clock inputs of high-speed processors and peripherals. This circuit is from Motorola's BRE272R3/D data sheet. *Motorola, Macro Marketing Ltd., Burnham Lane, Slough, Berkshire. 06286 4422*

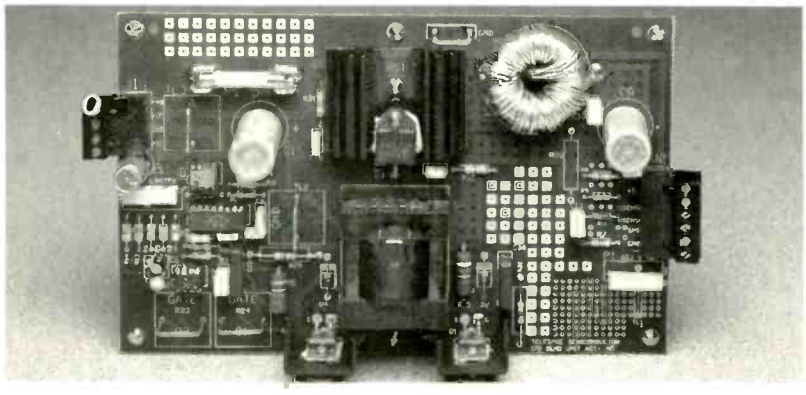


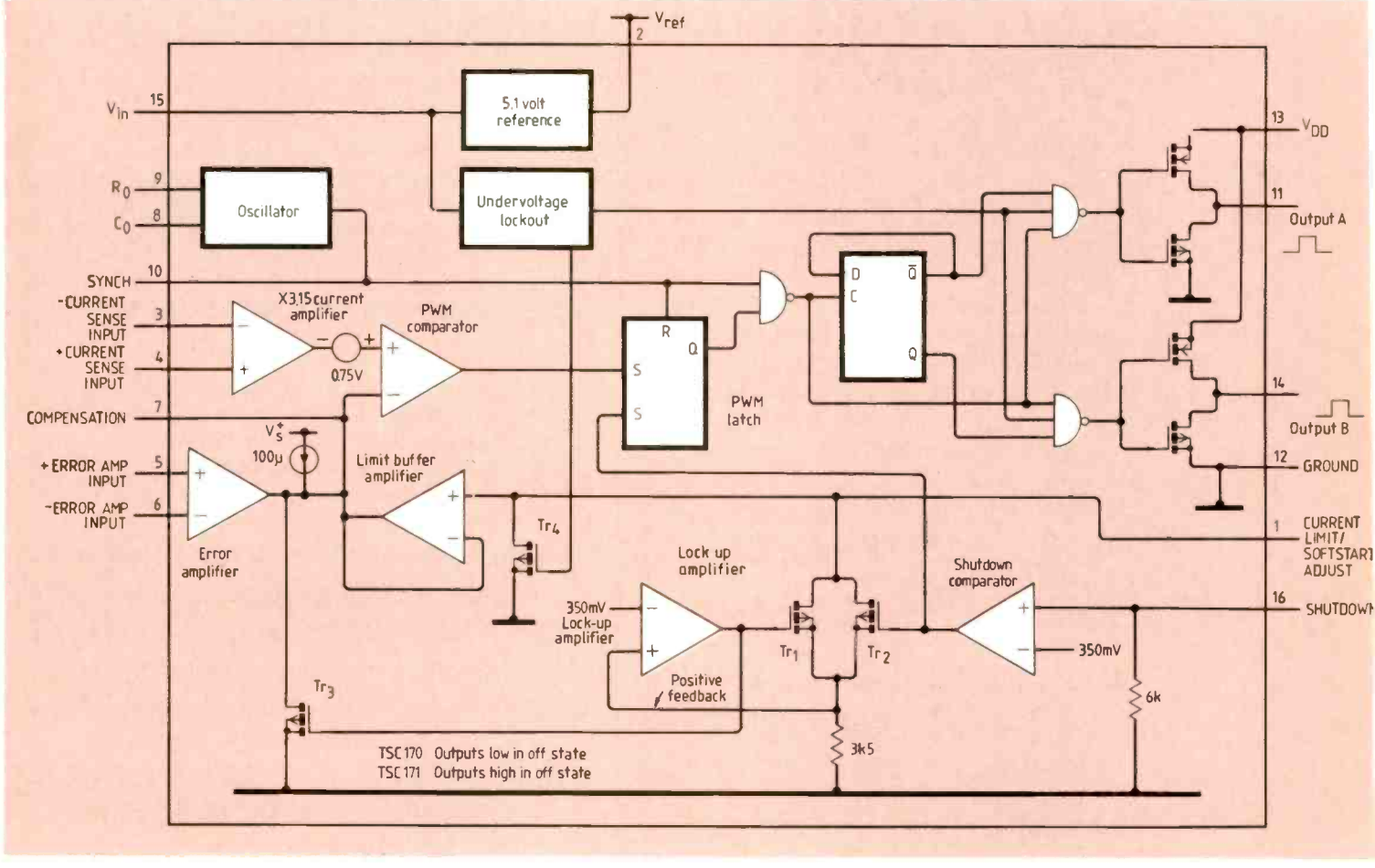
CMOS SMPS controller

According to one of two recent notes on the TSC170 cmos PSU controller from Teledyne, current-mode control in pulse-width modulation is still not well understood.

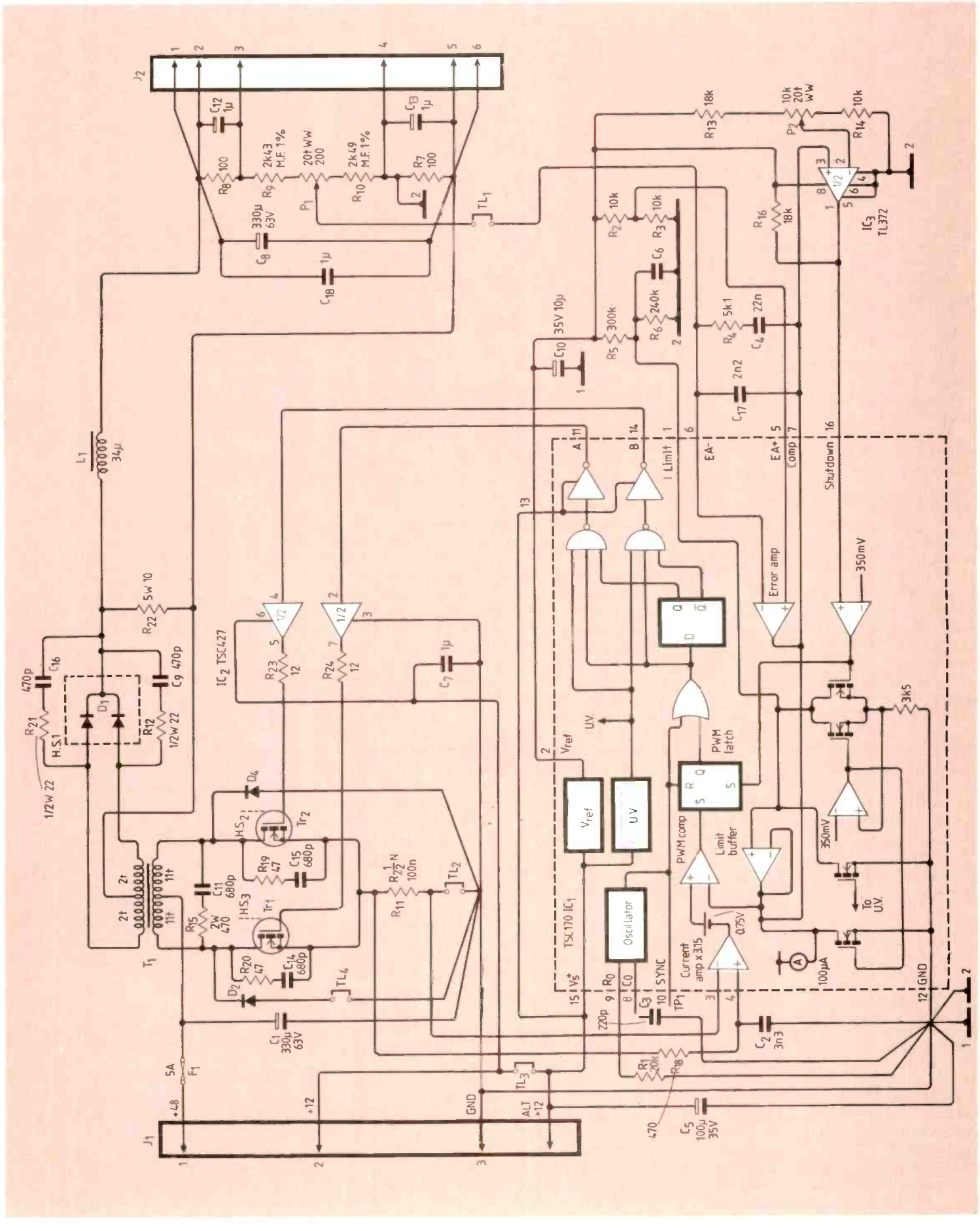
Application note 32 discusses current-mode control, particularly in relation to the TSC170 controller, and note 34 details a demonstration/evaluation board designed around the 170.

This circuit, from note 32, is that of the evaluation board. It is a 100kHz switching power converter delivering 25A at 5V and its efficiency at 15A is 80%. The converter is a DC-to-DC type using a push-pull configuration; its oscillation frequency is fixed and the control scheme is current mode with p.w.m. *Teledyne Semiconductors, SSI, Dawson House, 128-130 Carshalton Road, Sutton, Surrey SM1 4RS. 01 643 1126*





APPLICATIONS SUMMARY



UK licences for public cordless telephones

MARTIN ECCLES

Services providing what the Industry Secretary Lord Young likens to "having a 'phone box in your pocket" should be operating before the summer. Lord Young has announced four Telepoint licences that will go to Ferranti and three consortiums involving Philips, BT and Mercury.

In the interests of getting the systems operational as soon as possible, the licence holders will be allowed to use their existing proprietary equipment but there is a stipulation that all the services must be operating to the same standard by 1991. Both BT and Mercury, being controllers of telephone lines, have been allowed only minority interests in the licences granted to their consortiums to ensure that they do not have an unfair advantage.

Ferranti, the only single-company licence winner and one of the pioneers of Telepoint technology, is to bring its Phonezone cordless-telephone service initially to London's M25 orbital area and then expand it into a national network along feeder routes.

Operating under the DTI's CT2 regulations for second-generation cordless telephones, the Phonezone service consists of microprocessor-controlled base stations connected to the public switched network and specially-designed cordless handsets for making outgoing calls within a 50 to 200m radius of the base station; there is no facility for receiving incoming calls in any of the Telepoint systems.

Since the radio link between the handset and Phonezone operates within a 4MHz section of the 900MHz band, the coverage radius will depend on the environment. Being digital though, there is no reason why the speech quality should not be excellent, except of course that it could be degraded by the public telephone network. Within the base stations, diversity is used to reduce the fading associated with multi-path environments.

In Ferranti's system, each base station links to a central terminal-management computer through the public telephone network. This link is not permanent; it is only made for example to update the base station's handset 'blacklist' or to update the central-computer's billing information. Should a fault occur in a base station, or if the zone becomes overloaded, the base station can call the terminal-management computer and off-load its data.

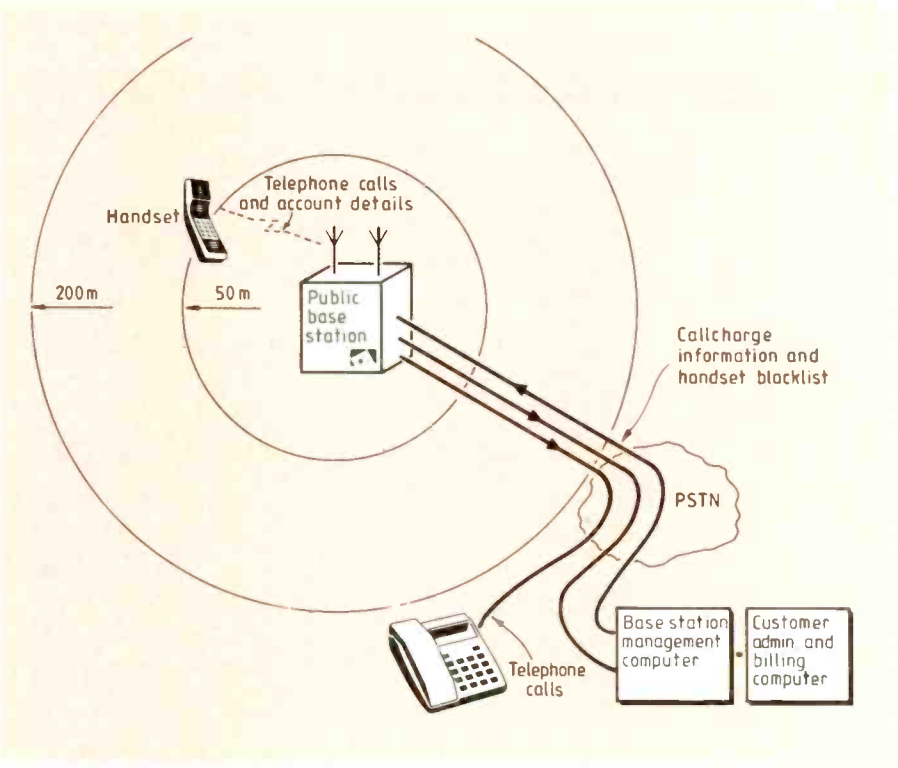
Each handset transmits its own code number, readable by the base station, and status information relating to that code is held within the base station microcomputer. This feature's main purpose is to determine who pays for which calls, but it also means that stolen handsets can be barred completely from use and individual company-owned handsets can be restricted for, say, inland calls only.

Ferranti says that to decode the digitised speech illicitly you would need a sophisticated decoder and a scanning receiver. Handshaking protocols prevent eavesdropping and unintentional overhearing of conversations and the handset is designed to transmit its code once every second while in use; if the base station does not see this code, calls cannot be made.

In relation to cellular telephones the Zonephone, with its relatively small microcell (zone) and frequency-division multiple access scheme, has a spectral efficiency 100 times greater. As a result, each square kilometre could accommodate up to 7700 users says Ferranti. In the future, user density could be increased even further by dividing microcells into picocells with a much smaller operational radius of about 5m.

Although the Zonephone's 4MHz spectrum between 864 and 868MHz divides into 40 channels, the user sees only one channel. Within the system's self-managing allocation system, the FM channels are allocated dynamically and are reallocated during calls to maintain optimum efficiency. This dynamic reallocation also complicates eavesdropping and accidental overhearing of conversations.

For a given caller, only one channel carries speech in both directions at any one time. This full-duplex speech path is achieved using time-division duplexing where alternate 1ms time slots carry digitised speech packets in each direction. Transmissions are restricted to 10mW.



In operation, the base-station/handset combination is like a large domestic cordless telephone but it works only for outgoing calls. The central computer, responsible for collecting status and billing information from the base station, updates the handset blacklist and requests all call information since the last poll.

CT-2 coming soon

RICHARD LAMBLEY

By April you could have this Forum CT-2 cordless telephone in your pocket. Not only would you be able to use it at home or in the office like a conventional cordless, you could also dial calls when out and about in public places (see *E&WW* December 'A cordless future' and Industry Insight page 1212). Its manufacturer, Shaye Communications, together with Mercury Communications and Motorola Ltd, will operate one of the four nationwide networks of public base stations (telepoints) and will call them Callpoints.

The Forum handset will also be used by the British Telecom consortium; and in addition, Shaye will supply the Forum for a pilot telepoint service in France.

Shaye and Motorola plan to install 2300 Callpoints in the first year, in airports, railway and underground stations, shopping centres, motorway service areas, hospitals and other public buildings. Price of the handset will be £150 + VAT and the domestic base unit another £150. Calls placed through a

UPDATE

Largest colour liquid crystal display

Thin-film transistors on glass have now been used to produce a prototype 14-inch liquid-crystal display with a resolution of 770 by 550 dots. The display is the result of a two-year joint research and development programme between Toshiba and IBM Japan. It is an active-matrix type similar to the one discussed in last month's issue but it has four dots per pixel instead of three – red, green, blue and white – and it is intended for 16-colour computer display rather than television.

In monochrome mode, the screen's resolution is 1440 by 1100 dots giving a total of 1.58 million pixels; pitch between each element is just 200μm.

Real-time i/o links into Lotus

Intelligent input/output hardware for getting data in and out of the Lotus spreadsheet in real time has been produced by Cambridge Microprocessor Systems. The PC plug-in i/o card, with its own microprocessor and language, is supplemented by enhancements to the Lotus 123 package.

Lotus enhancements, in the form of extra @ commands, not only allow reading of data into a cell but also allow writing of data from a cell to the i/o system in real time. A cell can be set to provide a conditional action; for example a cell can be set so that an action is taken if the numeric value within the cell is greater than 99. "With these enhancements, Lotus almost becomes a language," says MD Phil Taylor.

Conditional actions are useful in factory environments for, say, giving a warning output when a tank level falls outside prescribed limits. It is possible to link the system output to a radio pager that will send out blip an engineer when, say, the tank is overfilled or empty.

Besides three serial ports, analogue input and digital i/o, the card has a network system that supports up to 255 remote stations. Radio-paging and modem interfaces combined with the board's real-time clock can be configured to allow remote monitoring at preset time intervals.

Controlling the board is a microprocessor running under a real-time event-driven language in rom that is programmed on the PC. An optional real-time data manager provides access to the board via pop-up menus regardless of the application running on the PC.

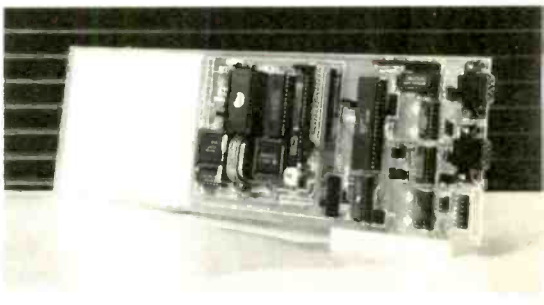
NCR joins 88000 risc group

A non-profit organization involved with promoting open standards for Motorola's 88000 risc processor now has NCR as a member.

The 88open Consortium, chartered in 1988, is pioneering a new type of business that relies on portability of 88000-based applications across a variety of hardware including fault-tolerant systems, file servers and workstations.

NCR is currently active in two 88open software development groups – one involving binary compatibility standards and the other a software initiative committee dedicated to the development of applications.

So far, the consortium has around 40 members, including America's Jet Propulsion Laboratory, Data General and Convergent Technologies.



Running under its own control language, this PC board links into Lotus so that data from an input port can be read, processed and sent out again through an output port, all in real time.

Callpoint will cost about one-third of the price of cellular.

Unlike most cellular handsets, the Forum is produced entirely in the UK, by Philips Components at Dunfermline. Shaye designed the unit with automated manufacture in mind and has made extensive use of surface mounted devices. It weighs only 130g. A replaceable lithium battery allows up to 50 hours of speech; or the user can opt for a NiCd battery giving three hours of speech. Range is up to 200m.

The domestic base station can handle up to six handsets, each of which must be registered with the unit to prevent use of the line by unauthorised callers. Every handset has a unique electronic serial number with an accompanying four-digit PIN, programmed into it during manufacture. To ensure good performance with the UHF signal (864-868MHz) diversity reception is employed in the base station. One antenna is hidden inside, but the other plugs into a socket on the case: this allows the user to plug in an antenna with gain, giving additional outdoor coverage if required.

CT-2 telephones in their first months will operate to proprietary transmission standards. Although a common air interface (CAI) has been agreed by the manufacturers involved, products meeting the standard will not reach the consumer until 1990. The switch to CAI involves both software and hardware changes and there is no possibility of upgrading early handsets; but Shaye and other manufacturers have undertaken to provide continued support for non-CAI products. This will involve the fitting of dual-standard equipment in Callpoints. The shape of CAI telephones is still being discussed, but one feature under active consideration is the inclusion of a radiopager, which would go a long way towards overcoming the restriction imposed by telepoint's inability to accept incoming calls. Shaye Communications is at Winchester on 0962-55925.

UPDATE

First complete optical switching

Scientists at BT's Martlesham Heath research laboratories have performed the world's first complete optical switching of short light pulses known as optical solitons, which can behave as particles, in a partially transmitting, optical-fibre Sagnac loop. The success indicates that the loop might become the optical equivalent to the transistor switch in conventional electronic logic.

In **Figure 1**, the loop takes the form of 100m of York polarization-preserving fibre, with its input and output arms coupled together in a 58:42 ratio fused-fibre coupler (A). The solitons, which are light pulses 0.4ps wide and not subject to dispersion, are launched into the loop via the lens and coupler B (76:24), which enables the input level to be monitored.

Since input and output of A are coupled, 42% of the input energy transfers from input to output, thereafter travelling in an anti-clockwise direction round the loop; the rest of the energy moves round in a clockwise direction. Since the coupler is unbalanced, the device possesses an intensity-dependent, non-linear response.

At low powers, transmission through the coupler is linear but, as the power increases, the transmitted energy increases steeply until at an input of 46pJ, transmission reaches 93% of the input. The ratio of soliton transmission to linear transmission is 36. At higher input energies, transmission falls and begins to increase again as the second cycle of non-linear response takes place.

This is the first time that all-optical, high-contrast switching of complete pulses at an energy of 46pJ has been reported, and indicates the feasibility of using solitons for extremely fast optical processing in fibres.

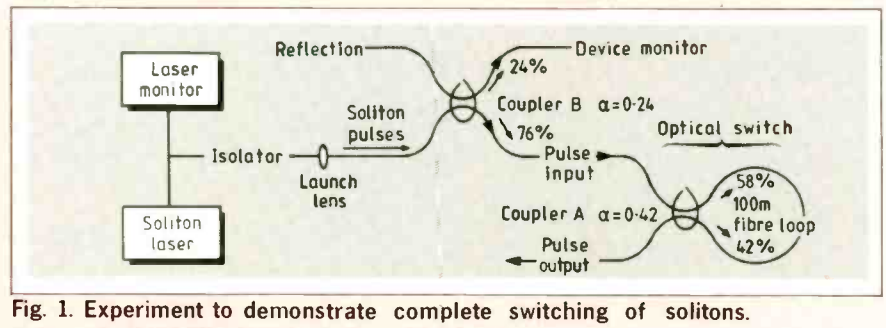


Fig. 1. Experiment to demonstrate complete switching of solitons. Pulse output is 93% of energy input to fibre loop.

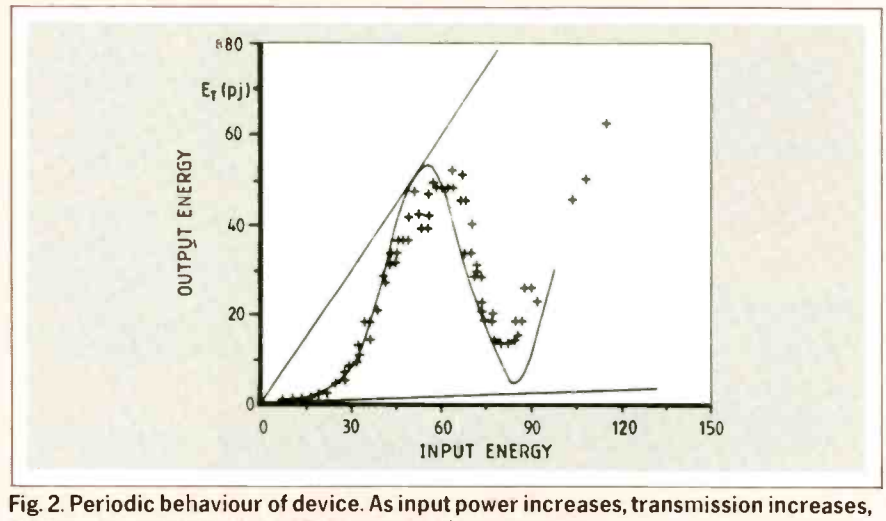


Fig. 2. Periodic behaviour of device. As input power increases, transmission increases, falls and increases again at 46pJ intervals of input energy.

Beyond VLSI

Frank Ogden reports from New York on a 32-bit processor from Inmos and on Anamartic's US *début*.

The International Solid State Circuits Conference held last month at the Hilton Hotel, New York City, is a meeting point for the world's semiconductor industry. It is an odd event, one never to be taken at face value. The industry's giants wave learned papers around, each the sum of many man years of work into semiconductor technology. But they are always half-truths published mostly for corporate image making, without giving too much away to the competition.

This year's event enjoyed a slight difference: the IEEE papers committee would only accept presentations on working silicon. Thus when Intel presented first details of a new general purpose microprocessor with a million transistors on a chip, the electronics world had to take notice.

The presented facts are these. The company proposes a million-device single-chip general purpose microprocessor with a risc processing core, 64-bit data bus, separate data and instruction caches together with on-chip floating point processing. Christened the 80860, it additionally provides a graphics management area for pixel interpolation and separate, directly implemented adder and multiplier units. The principal internal data pathways are 32 bits wide while the three separate computational areas of the chip – FPU, adder and multiplier – can execute instructions in parallel to provide up to three operations per clock. All this, says Intel, results in a chip measuring 10 × 15mm which achieves 105 000 dhrystones, 21 million floating point operations per second at a clock rate of 50MHz. This is about five times the performance of an 80386.

What does it all mean? Firstly, the architecture is a complete departure from everything which Intel has offered up until now. The instruction set is new and specific to the device; the only similarity with the 80X86 family is an ability to crunch 32-bit data words, albeit at a prodigious rate. This means that prospective users will have to develop a device-specific operating system. DOS and OS/2 go out of the window unless running under an emulation program.

The heavily pipelined architecture implies fast execution of multitasking operations given a suitable operating system. This, and the extremely powerful concurrent graphics and floating point computational mechanisms would make the architecture ideal for workstations running under Unix and other multi-user environments. In the past, semiconductor companies have been inclined to talk glibly about "mainframe power in a microchip" when, all along, you have known the claim owes more to public relations than performance. We can begin to believe on this occasion though. It is no exaggeration to say that the workstation world, having messed

UPDATE

about with SPARC and other multi-chip risc architectures will probably be grateful for this one if Intel proves capable of making the enormous die in volume. Intel's architecture will give the DEC minicomputer market much to think about.

If the Intel processor announcement held the greatest significance for systems design engineers, numerous papers on devices fabricated from a mix of bipolar and cmos technology indicated a process technology trend initiated by the semiconductor industry itself. A 500 000-device 32-bit microprocessor from Hitachi has been shown to operate up to 70MHz clock rate by virtue of a mere 8000 bipolar transistors strategically placed at critical nodes. Power dissipation was said to be just over 2W at 40MHz clock.

The theory behind bicmos is simple. Standard mos devices require very little power, particularly in the quiescent state. Their small geometry allows large arrays to be manufactured – for instance memory sections of processor chips. However, the very limited drive capability inherent in small fets tends to slug signals coupled into long runs across the chip or, even worse, when coupled to the outside world. The exponential base-emitter voltage relationship found in bipolars enables very high output currents to be generated from very small voltage swings. Combine the two sorts of devices and you have an almost ideal solution to designing VLSI and beyond: low power consumption without speed penalties. But there are other penalties. Bicmos requires significantly more process steps with a consequent decrease in yield and an increase in production costs.

The Anamartic wafer scale paper played to a full house drawn by the prospect of the world's first viable whole wafer product. The specification has undoubted commercial appeal: 200Mbit of serial memory organised as 50 million four-bit parallel words. The company quotes an average access time of 10μs with a worst case of 20μs to any individual bit. This represents a data transfer rate of 20Mbit/s with an active power consumption of around 3W/wafer.

The wafer uses 1 Mbit rams interconnected by a network of self-configuring, fault-tolerant control logic blocks. These blocks interact with each other to form a spiral of good memory.* The configuration process automatically maps bad sectors of memory within the individual drams to an external eprom. Each ram also contains a DC power switch to remove devices which present short circuits to the power rails. Taken together, the redundancy techniques allow the use of partially operational ram die within the memory spiral. The configuration system will also automatically bypass areas of the wafer caused by defective logic blocks.

The wafer uses common power rails, clock line (20MHz) and a single command line. It is essentially a seven-pin serial device. It wire-bonds to a PCB which also contains external control logic and the error map eprom.

The dynamic refresh of the individual ram chips would normally cause power spikes if an attempt were made to refresh all parts simultaneously. Each control logic block contains a refresh counter which provides a skewed output in relation to neighbouring blocks.

The ram core and logic blocks have been produced on a Fujitsu process using 1.3 micron design rules: individual ram dice are some 20 per cent larger than standard 1Mbit drams. Each control logic block is equivalent to around 1200 gates.

Full ISSCC report next month.

* Pictured in Industry Insight, page 385.

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74HCT138	0.23	0.16	8085	1.60	1.00
74HCT373	0.35	0.28	6522P	2.80	1.85
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FEEDBACK

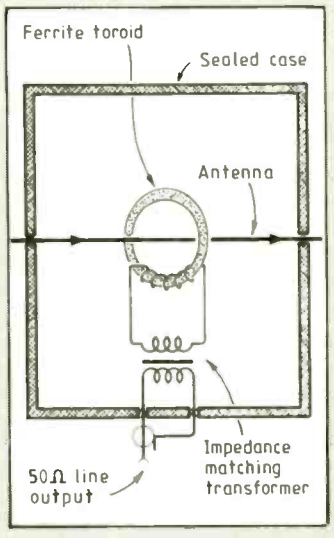
Faster than light?

I would like to reply to the numerous letters in the March issue of *EWW* on the article by Alexis Obolensky and myself which appeared in the December 1988 issue.

Despite the criticism resulting from the almost unbelievable outcome of the experiment, the findings withstand all scrutiny. The main conclusion is effectively without error and is that certain electrical signals propagating in wires exceed the speed of electromagnetic waves propagated in the same wires, that is that they exceed the velocity of light (by definition) propagated in wires; the velocity of fast signals in one case exceeds the velocity of light by a factor of at least 100.

All the critics agree that the received signals are not an artefact of the oscilloscope, but are indeed signals transmitted from the source to the oscilloscope. Alternative explanations offered varied greatly, contradicting each other in the process. Some attributed the results to an undetermined propagation mechanism, while others asserted that the signal took a short cut through the air rather than along the lines. Some respondents disputed the propagation path, others the transformer coupling and still more said that the received signals were not emitted simultaneously by the source, or even mentioned many sources.

In reply, I should point out that the impetus for the experimental method, used for the first time in August 1988, was to determine the velocity of signals using one clock, that of the oscilloscope, and several one-way routes. This "one clock, many routes" method seems paradoxical since relativity teaches that, to measure the one-way velocity of a signal, one has to use at least two synchronized clocks and one "one-way" route. However, elementary considerations show that, since speed is the distance of propagation over the time lapse, it can be determined by an analysis of the relative delays of signals travelling different routes of known



lengths.

The first lemma established in 1988 was that the relative delays in various propagation trials were always proportional to certain path lengths in the experiment. This is the most fundamental relation established in the experiments, because it shows beyond any doubt that the conclusion reached, that the speed of the signal was faster than light *in vacuo*, is correct. However, a gremlin crept into the article and caused the proportionality to be expressed incorrectly as an "inverse" proportionality. I apologize for the error, but the method and the data stand correct.

The proportionality lemma (PL) guarantees that all the signals were emitted simultaneously, or the result would have been linear, rather than proportional. Similarly, the PL proves that the source of the signal is one point – the energized relay. It excludes the possibility that the signals took a common short cut for both channels, since the delays varied in proportion to the lengths of the lines; and also the possibility that the signals were surface signals, penetrating at the first random loss of shielding. The transformers imposed no practical delay or any other adverse effect; they were high-quality, sealed, fixed units made by Tektronix (CT1 and CT2), connected according to specification. The remark that the coupling might have been capacitive is irrelevant, since a totally capactive coupling would not change the analysis.

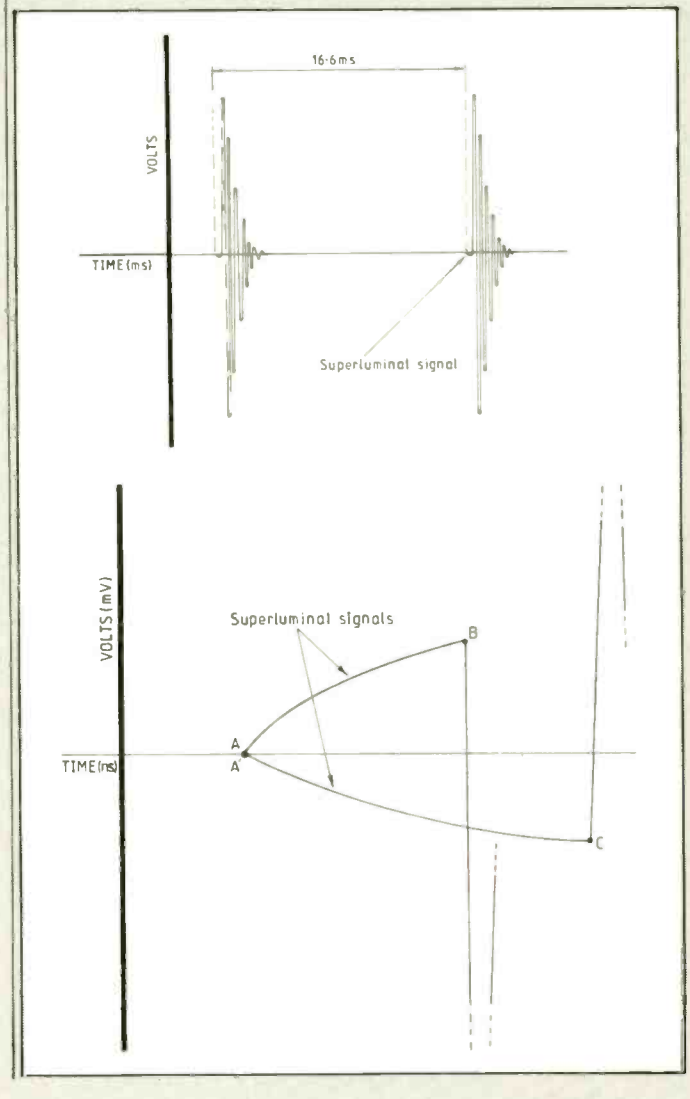
The shielding of the coaxial lines and of the oscilloscope were normally grounded at the oscilloscope. Unplugging one cable and taking no other precaution made the corresponding trace flat, the other remaining unaltered. This proves that the two simultaneous signals had no common path and that each arrived via its own cable. If the inner of either cable was broken at any point, the connections remaining, the corresponding signal was lost.

The exact value of 2c derived for the second, faster-than-light velocity, though smaller than the first velocity of over 100c, seems to be the only error in the text and is solely my responsibility. The exact value of this velocity depends on the velocity C_1 of the waves propagating in the coaxial lines, for which the article provided limited data and accuracy. This value C is given by

$$1/c' = 1/C_1 - 1/c_1$$

the c_1 on the right-hand side being the value given in the article. The value of c' can be anything from the ordinary signal velocity C_1 to infinity, depending on the characteristics of the line. My improper definition of c_1 can be attributed to an effort to prove its inherent identity to the PL. This definition proves this fact and consequently the two simultaneous signals may be considered as two (somethings) that propagate at a constant velocity before the main pulse. The major conclusion of the article remains correct.

P.T. Pappas
Athens
Greece



FEEDBACK

Instrumentation amplifier

The circuit described by Nanno Herder (Broadband Instrumentation Amplifier, *EWW*, September, 1988) deserves a more complete analysis.

If all three operational amplifiers have gains α_0 and bandwidth ω_0 the differential gain is

$$g_d = \frac{a+1}{1+j\frac{\omega(a+1)}{\omega_0\alpha_0}}$$

and the common mode gain is

$$g_c = \frac{\frac{a+1}{a\alpha_0}\left(1+j\frac{\omega}{\omega_0}\right)}{1+j\frac{\omega}{a\omega_0\alpha_0}-\frac{\omega^2(a+1)}{\omega_0^2\alpha_0^2 a}}$$

where it is assumed that $\alpha_0 \gg a$.

The differential bandwidth is therefore $\omega_0\alpha_0/(a+1)$ but at this frequency the common mode gain has reduced to $(a+1)/[(a^2+a-1)^2+1]^{-1/2}$ which is 3dB for a = 1 and so does not have the advantage that Mr Herder claims.

The standard instrumentation amplifer (Fig. 1 in the article quoted) uses the first stage for gain and the second for CMR. Mr Herder's development of this circuit improves the CM rejection ratio of the first stage and so makes the resistance values of the second stage less critical.

K.G. Barr
University of the West Indies
Bridgetown
Barbados

High-definition TV

In all the talk about HDTV it seems to be forgotten that, after World War II, France had a monochrome TV system with 819 lines. After visiting France in 1956 I wrote a note in *Wireless World* (May 1956, pp 239-240) in which I commented favourably on the system but was critical of French studio and camera technique: at that time the argument in Britain was whether we should scrap the 405-line system! The French system of monochrome HDTV used channels of 10 MHz, whereas most of the systems with lower definition, with or without colour, used 5 MHz. It was probably the pressure on availability of channels which caused the abandonment of this system at the same time as colour was being introduced, since any of the interleaved colour systems could have been tailored to any number of lines per picture. At present there seems to be enough bandwidth available on satellite transmitters (DBS) to provide more lines and non-interleaved colour; but if with increasing usage there is eventually pressure on frequency allocations, the answer next time might be frequency-compression of the picture information, via digital processing, without reducing the number of lines per picture.

D.A. Bell
Walkington
Beverley

The current use of high-brightness, large-screen TV receivers causes artefacts such as cross colour and cross-luminance patterning, which are due to the frequency multiplexing of the luminance and chrominance components, to become obvious to viewers. But are they worried by this? The quality of reproduction achieved by many mass-produced VCR's, combined with video library tapes, seems to suggest not.

Does the viewer want HDTV? Market research in Canada and the United States, though somewhat confused on this point, suggests that HDTV is acceptable if the cost is right. From Japan, it seems that a nationalistic interest might drive their market. However, one point is quite clear: programme material has to be something special to encourage the consumer interest.

The artistic need for better-definition television is not in doubt. But which of the many proposed systems would produce the best results? The oneupmanship concept will always ensure that a small minority will purchase even non-compatible systems. Perhaps if suitably nurtured, this small, select customer base could ultimately expand to provide a wider acceptance for a new service. Whilst not in quite the same category, this happened with the VCR, but not with the video disc player that gave far better video quality.

The two main contenders for a world HDTV standard are the Japanese NHK Hi-vision and the European MAC systems. Both avoid the cross colour/luminance problem by time-multiplexing the video components. Wtih a video bandwidth in excess of 30 MHz, both produce high-quality images when displayed on full-bandwidth, high-definition equipment. That either system is suitable for use as a production standard is not in doubt. It has been adequately demonstrated by the NHK system that quality can be as good as 35mm film and is economical even when transferred to standard cine film. However, major problems arise when bandwidth compression has to be employed to force these signals through a normal TV channel.

The NHK Muse system that has been demonstrated many times uses sub-sampling during encoding and interpolation and motion compensation at the receiver. After viewing many of these demonstrations, it is obvious that artefacts are present. When multiple-direction movements are present and accompanied by signal-level changes, a defocussing effect is shown, whilst diagonal movement of striped material produces a strobing effect. At times these can be more annoying than the cross-colour/luminance problems in PAL.

The European HDMAC system was first publicly demonstrated at IBC'88. This also uses sub-sampling, but includes a digital assistance signal that helps the receiver to cope with motional decoding. These pictures were judged to be good, particularly since the demonstration was mounted after only two years of European cooperation. However, these images were not as artefact-free as those previously demonstrated using 625 line C-MAC or D-MAC. It is therefore important that this system should be carefully viewed to ensure that it does produce better results.

It is well known that image impairment is context sensitive. Viewers are less critical of poor quality in scenes that carry a lot of movement, or in images where the interest is concentrated into a small areas. The experts subjectively judge image quality using a viewing panel, placed at a distance of three or four times picture height. Is this realistic when the average family group views the screen from about twice this distance? Before we judge standards, should we not also judge the way in which practical comparisons are made?

One final question that should be addressed involves the programme material so far presented at demonstrations. How much preselection was applied to avoid the known artefacts that might have been seen under more normal conditions? Unless demonstrations can be seen to be free from such bias, there is a good chance that we shall simply exchange one set of artefacts for another and pay dearly for the privilege.

Geoff Lewis
Canterbury
Kent

Anti-gravity

In the box on page 30 of January's *E&WW* H. Aspden described the force-precessed gyroscope. His final sentence is "The fact that the machine develops a sustained lift force in defiance of Newton's Third Law is undisputable, owing to the placement of the demonstration machine on a balance with a knife edge support and the use of counter weights."

Oh yes it certainly is disputable! From his description (which I could not understand) of the machine, it seems that the 'lift' force is of a pulsed nature. Weighing machines are designed to measure a steady force. Their behaviour when subjected to a pulsed force of large 'form factor' could be anywhere between peak-rectification and peak-ignorance. The latter case might well apply if an electronic balance was used, giving rise to an apparent weight reduction.

David Williams
Epsom
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PIONEERS

28. Russell and Sigurd Varian: "One day, he'll make the big invention"

Electronics laboratories do not usually manufacture blackberry jam. But when the first official visitor arrived at the newly-founded Varian Associates in August 1948 he found the jam pot merrily bubbling on an electric cooker and sterilized jars waiting to be filled. The Varian brothers, Russell and Sigurd, already had a reputation for their invention and development of the klystron and they were known to do things in unusual ways.

The visitor, a government official sent to survey the company's facilities, later said that he would not have been surprised if the jam making had been one of Russell's experiments. The truth was more prosaic. Sigurd's wife, Winnie, did not want to waste a good harvest of blackberries.

About Christmas, the same official received a jar of jam through the post, the last of Varian Associates' first product line. Sorry, he was told, but re-orders could not be accepted though they would be happy to discuss any requirements for klystrons or travelling-wave tubes.

So began the corporate life of Varian Associates, an international company now just over 50 years old and long famous for its klystrons which are used in such diverse applications as television broadcasting, defence, medicine and industrial production. Like the cavity magnetron, the klystron as a device of high power and high frequency came along at the right time to help the Allied cause in the Second World War.

CHILDHOOD

Ever since childhood Russell had made inventions and Sigurd had built them. As adults they went their separate ways but were united by strong family ties; Russell struggled to follow an academic career, Sigurd became a dare-devil pilot. Throughout, however, both dreamed and made inventions with Sigurd never losing faith that one day Russell would invent "the big one" which would put them on the path to riches and independence. Eventually, he did.

Russell Harrison Varian was the eldest son of John Varian and his Australian-born wife, Agnes. It was Agnes who bonded the family together. John and Agnes emigrated to America from Dublin before the turn of the century and settled first in California before moving to Washington DC, where Russell was born on April 24, 1898.

From Washington they moved to Syracuse, New York, and Sigurd was born there on May 4, 1901. John suffered from asthma and bronchitis and the family's fortunes went up and down. After four years on the East Coast John lost his job and for a while it looked as if the children would have to be cared for by Agnes's sister. Friends and relatives persuaded them back to California where they settled in Palo Alto in 1902. It was there that their third son, Eric, was born on June 16, 1904.

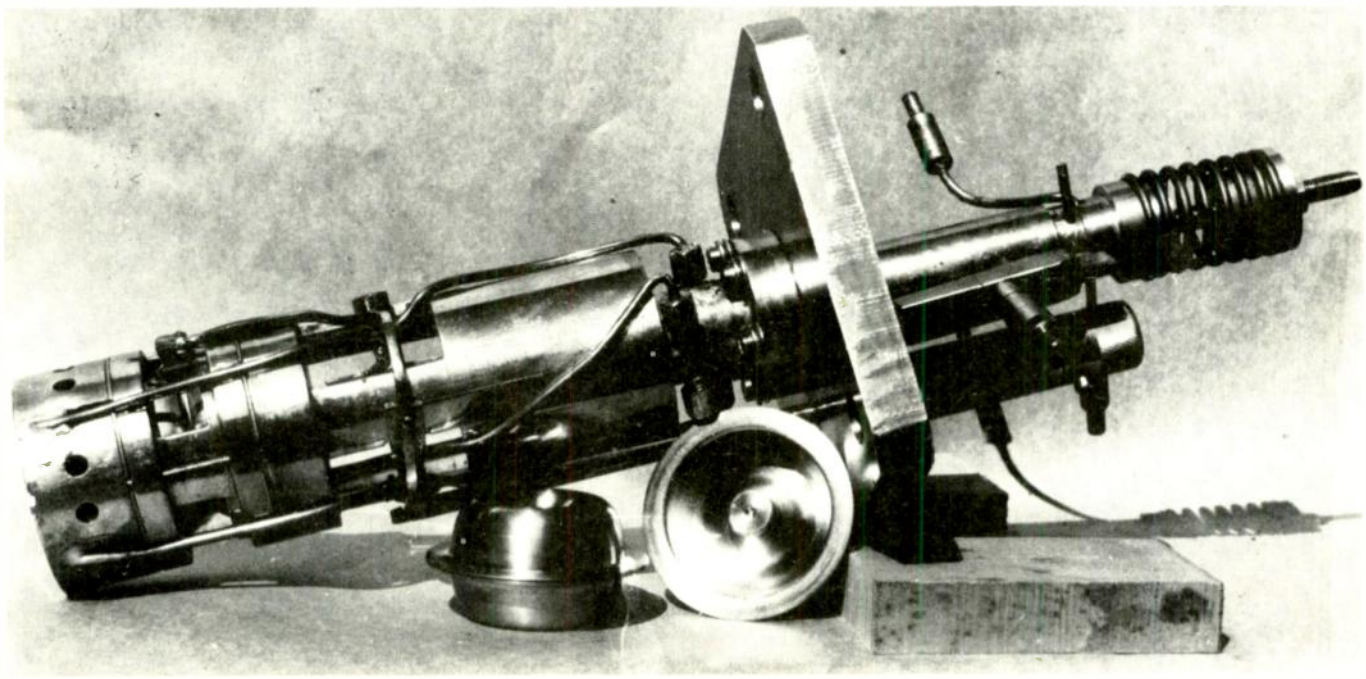
An elderly aunt provided a house, John became a masseur, and life improved. The boys developed a healthy outdoor life-style – and the usual indoor one too, as a letter from their mother reveals: "When I got home from San Jose the boys had the house as if a cyclone had gone through it, leaving the dirt from the entire neighbourhood. They had taken it into their heads to make doughnuts and spilt grease all over the floor in great patches, had pillow fights in the parlor and generally played Old Harry." Training the family dog to pull them along on roller skates was another indication of their adventurous spirit[1].

But their spirit of adventure must have been satiated on the night of April 18, 1906, the night of the San Francisco earthquake. The entire family escaped unscathed; but cycling around to see the damage, and particularly the displacement at the San Andreas fault, made a big impression on Russell.

When the boys were in their teens, life once more became hard. A new law required all masseurs to be registered, but John was self-taught and could not get a licence. His clientele dried up. In 1914 the family moved to Halcyon, also in California, where they took over the post office and general store – taking with them the family dog, Russell's beehives and two donkeys. Through inheritances, gifts and loans they bought the shop, its stock and, eventually, a house. "They managed", wrote Dorothy Varian, "but the income from the post office and store was barely enough to keep food on the table."[1]

The house took on a cosmopolitan atmosphere as various guests, paying and non-

Model A, the first klystron, August 30, 1937. It gave continuous output at 13cm. Pictures by courtesy of Varian Associates Inc.



paying, moved in from time to time, some for treatment from John. All were treated with love and some were considered as members of the family. Nan, a lonely Irish girl, was regarded as an adopted niece until her death from tuberculosis – from which Sigurd was later to suffer repeatedly.

Meanwhile the boys made things for amusement, Sigurd stripping old car engines and Russell learning about the audion bulb (the original thermionic triode).

RUSSELL

The Varian boys attended grammar school in Palo Alto and high school near Halcyon. Russell left to work his way through Stanford University to a bachelor's degree in physics, which he received in 1925. Two years later this was followed by a master's degree – a considerable achievement for someone who, as a boy, had been held back by a few years at school because of his appallingly bad reading and spelling, caused possibly by dyslexia. This awful spelling was to stay with him for life. It was sheer persistence and a refined intelligence that saw him through. Even his career as a student got off to a bad start as surgery and illness wrote off his first year.

Ideally the next step would have been a Ph.D., and a life in academic research, but that was not to be. Sigurd was ill with tuberculosis and his parents needed financial help from their eldest son. Bell Labs turned him down but he got a job, for six months, with Bush Electric in San Francisco. This was followed by a research post with an oil company in Texas. After five months he was dismissed, almost certainly because of personality clashes with his employer. It was some compensation, however, that he had been awarded his first patent.

Back in San Francisco he was offered a position with the Farnsworth Television Laboratory. This was 1930, and America's economic structure was in chaos. But television research was progressing in several places and Philo T. Farnsworth's image dissector was acknowledged as one of the leading contenders. Russell Varian was delighted to join in the fun, even when a change of financial backer meant a move to Philadelphia. By mid-1933, though, problems between Farnsworth and Philco, the new backer, led to Farnsworth's pulling out and shutting down. RCA went on to win the race to produce electronic television in America and Russell returned to Stanford. He applied to study for his long-awaited Ph.D. and was astonished when he was turned down.

At 36 years of age, his future had collapsed. He trained as a teacher but never took up the profession. Instead, at the university he did some tutoring here, some marking there, and what research he could. This prompted Sigurd to ask, "Is Russell figuring on making money out of scientific papers, or is he just going to advance the cause of science for nothing?"

SIGURD

Sigurd Fergus Varian left school in 1920 and registered at California Polytechnic but quickly dropped out. He was far too adventurous for the academic life. His contribution was not to be the original researcher but the developer and implementer of ideas, the man who got them to work. With a friend, he set up his own business as an electrician, but then joined the Southern California Edison Company. When stringing high power lines near a small airfield, Sig (as he was known) became fascinated by the aeroplanes. Soon he was receiving flying lessons at $4 each. It was the start of a life-long love affair. After two months he could write home, "I can make a peach of a landing".

In August 1924 Sigurd bought a wartime biplane. Soon the plane was earning money with stunt flying, advertising, selling lessons and giving joy rides. But by now tuberculosis had struck for the first of several times and six months' rest was needed to clear his lungs. The next year he hired himself out to an electricity company as a flying serviceman and used his plane in other ways to earn a living. By 1926 regulations for flying were being introduced and Sig, and his plane, were duly licensed.

The life he was leading took its toll, however, and tuberculosis struck again. This time it was severe and Sigurd spent a year in a sanatorium, a severe trial for one with a driving, adventurous nature. When he finally accepted his fate he used some of his invalid time to plan for the future and study aerial navigation. He also made his first request to Russell to help improve aircraft navigation instruments: a radio compass was their first serious project, though it did not work out.

Sigurd decided it was time to get a regular job with an airline. He was an excellent pilot and was signed up by Pan American for its subsidiary in Mexico. The job turned out to be extremely well paid and had more than its fair share of excitement, with hunts for emergency landing sites, revolutions and other thrills. He also met and married Winifred Hogg, the daughter of the British consul in Vera Cruz and who, years later, was to make that blackberry jam. Mexico was also where Sigurd learned about the hazards of aircraft navigation and the need for aids, especially for blind landings. The threat of another war in Europe worried him and he pondered how approaching aircraft could be detected. Meanwhile the postmen carried letters to and fro between the brothers as they exchanged ideas for inventions and businesses.

By 1935, Sigurd was ready for a change. He took six months' leave and he and Winnie headed for Halcyon and a home laboratory which he set up and shared with Eric and Russell.

VELOCITY BUNCHING

"Just picture a steady stream of cars from San Francisco to Palo Alto; if the cars left San Francisco at equal increments and at the same velocity, then even at Palo Alto they would be evenly spaced and you could call this 'a direct flow of cars'. But suppose somehow the speed of some cars as they left San Francisco could be increased a bit, and others could be retarded. Then, with time, the fast cars would bunch into groups. Thus, if the velocity of cars was sufficiently different or the time long enough, the steady stream of cars would be broken and under ideal circumstances would arrive in Palo Alto in clearly defined groups. In the same way, an electron tube can be built in which the control of the electron beam is produced by this principle – bunching – rather than by the direct control of the grid of the triode."

Russell Varian's description was recalled by Edward Ginzton.

THE KLYSTRON

During his time at Stanford, Russell and built up friendships; and one especially, with a physicist called Bill Hansen, was to blossom. Hansen worked on X-ray phenomena and microwaves. Early in the Second World War his teaching notes were classified and used at the famous MIT Radiation Laboratory, where much of the American work on radar was performed and co-ordinated. Before that, however, with Russell Varian he speculated on how to get "high velocity electrons without spending a lot of money".[2] The result of Hansen's work was the rhumbatron (named after the rhumba dance), a cavity resonator which was to feature in the invention of the klystron.

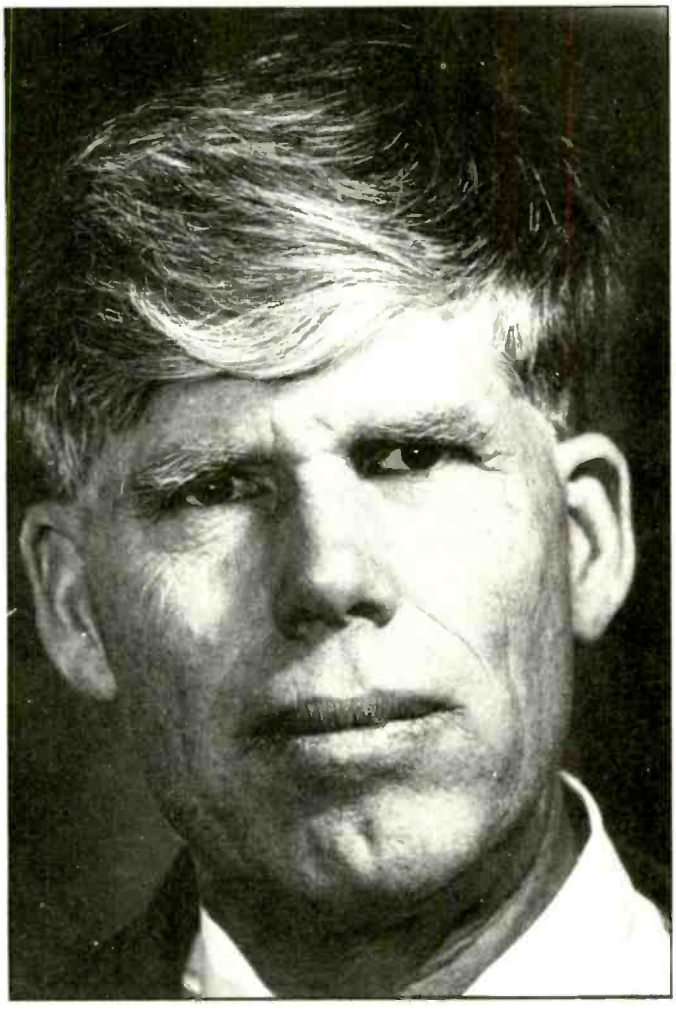
When Russell arrived at the home laboratory, Sigurd and Eric were busy developing earlier ideas and still hoping that Russell would invent "the big one". Cities were being bombed in Spain and China, and aircraft detection was high on Sig's list of priorities. They knew that short wave radiation would be suitable but there was no way of generating the high powers required. Of course they did not then know of the secret military work on pulsed radar.

Russell recognized the need for a resonator and thought of Bill Hansen's rhumbatron. He and Hansen talked it over in May 1936 and Russell developed his ideas further. In February 1937 he had the design for a microwave tube and sought permission to use Hansen's resonator and one of Farnsworth's inventions (which was later dropped). Other ideas developed and Russell came to realise that completion of the project was beyond the resources of their little laboratory.

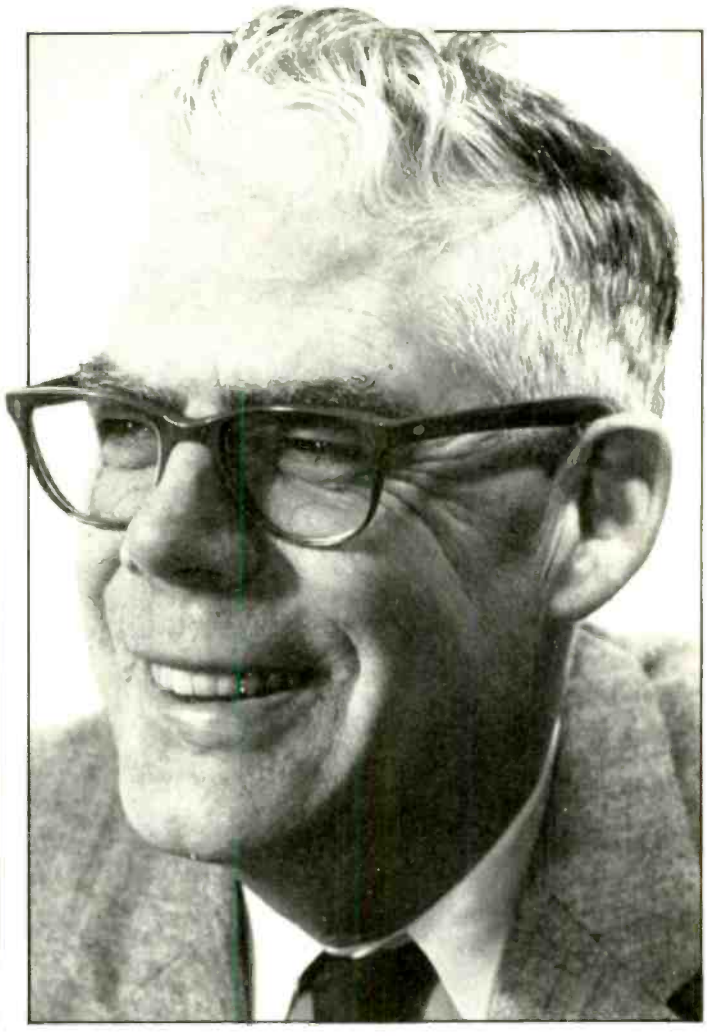
Sigurd's drive and determination saved them. He believed this was the "big one". In the past he had obtained the facilities he had needed for the ill-fated radio compass by enrolling on a course at California Polytechnic and using its workshop, and he had also fixed the occasional plane there. Now he proposed to use the laboratories of Stanford University. Russell hesitated, Sig did not. By the end of April they had an agreement with the university that it would provide facilities, the right to consult with staff, a research grant of $100, but no salaries. In return, Stanford got equal shares of any financial return. It was a good deal all round.

A HAMBURGER CELEBRATION

Once they had started, many ideas and variations on ideas tumbled out of their minds. So much so that on June 5, 1937, Russell decided to sit down and classify them



Russell Varian



Sigurd Varian

all to ensure nothing was overlooked. It was whilst doing his classification that the fundamental idea for the klystron, the velocity grouping or bunching principle, struck him. Sig remembered the date clearly: it was the day he blew the main breaker in the university power house.

With a determined struggle they completed the design and built the first klystron, overcoming many problems on the way. The completion of the first hand-filed hexagonal grids called for a hamburger celebration. Building their own detection and measuring equipment proved to be another important problem; and solved it was. In two months the Model A 10cm klystron, encased in a vacuum bell jar, was working – intermittently – on August 19, 1937. By the 30th the device had been rebuilt and gave continuous operation at 13cm. It had cost $50 of Stanford's money.

Up to then the device had been known as the "thing", the "can" and the "spittoon". A respectable name was needed. "Tron" was a common suffix for a vacuum tube and "klyso" was chosen as representing the bunching of waves on a beach, hence klystron.

Further detailed development work was needed. Instead of just three men (Russell, Sigurd and Bill Hansen) a whole team was now involved and a lot more effort and money was needed. Sperry Gyroscope agreed to fund the work with up to $25 000 a year. Suddenly it was big business.

The relationship with Sperry, industrial production and war-time use of klystrons are stories in themselves. The brothers were not cut out to accept direction of their ideas and their work from others and the relationship with their new employer involved several conflicts. Facilities were moved from California to the East Coast. Russell was engrossed in the vital patent applications and Sigurd's terrier approach to his work brought more tuberculosis and wrote him off for almost another year. At one stage, it was rumoured that Sperry wanted to buy the patents and sack the pair of them. It is not surprising that the brothers and their friends laid plans for their own post-war research laboratory.

In mid-1946 Russell returned to Palo Alto, depressed by the failure of his five-year-old marriage. But things were about to improve. He took great joy from hiking and camping and in 1946 he married a fellow camper, Dorothy. This marriage lasted until his death in the great outdoors of Alaska on July 28, 1959.

The time had come for the long-discussed laboratory to become a reality. Russell found a suitable building measuring 30 by 40 feet on an unpaved street in San Carlos. It was cheap. On April 20, 1948, Varian Associates became a legal reality. Sigurd arrived in May "full of energy and enthusiasm".[1] A sum of about $45 000 was needed of which the partners could contribute only $23 000. A new recruit added $5000 but that still left them $17 000 short. Their distrust for big business ruled out going to financiers and it was Bill Hansen who once again stepped in to help. Hansen was then a sick man and would not live another year, but he provided the remaining money, possibly by mortgaging his house. Varian Associates was established.

Honours came their way, including medals from the Franklin Institute and an honorary doctorate for Russell, who had been denied the chance to work for one. Sigurd continued to be plagued by poor health and in later years he spent more and more time in semi-retirement at his home in Mexico, building a workshop and inventing.

On 18 October, 1961, he was flying parts for his workshop back to his Mexican home. It was dark and the airport lights were out. He decided to land on the beach, crashed and was killed. It was probably the way the great adventurer would have wanted to go.

References

1. Dorothy Varian. The Inventor and the Pilot. Pacific Books, 1983.
2. E.L. Ginzton. The $100 Idea. *IEEE Spectrum*, 30-39. February 1975.

The author expresses his thanks to Varian Associates Inc. for contributing information for this article.

Tony Atherton works at the IBA Harman Engineering Training College, Seaton, Devon.

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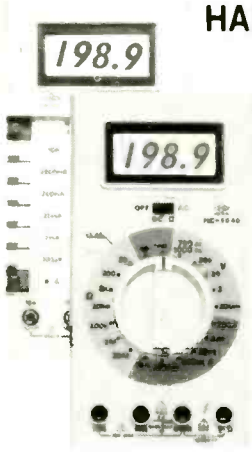

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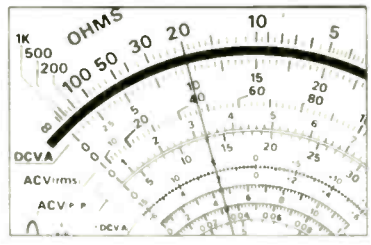

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COCOM: Arguments for change

The Co-ordinating Committee for Multilateral Export Controls (COCOM for short) is an informal NATO body which imposes constraints on the export of electronics to the Eastern Europe. The idea behind COCOM is simple: how can the West maintain its lead in strategically sensitive technology, if the Russians can buy similar technology on the open market?

Thus, every export to the Warsaw Pact countries must be checked against the COCOM rules; this can take a minimum of twelve weeks and any member country in COCOM can veto a particular sale. The results can be bizarre: in one case the spares for a teleprinter were banned, whilst the teleprinter itself received the go-ahead; in another, a microchip used to dispense vodka automatically received the 'thumbs down'.

However, as East-West tension relaxes, the economic stakes are becoming increasingly high. Over the past five years, several MPs have raised in Parliament the suspicion that the USA, the most influential country in the COCOM structure, uses the rules to give USA companies first chance at the new and potentially lucrative markets.

All these issues were considered in a public examination of civil servants, Government and representatives of companies such as Ferranti, ICL and Rank Xerox. The result, a report[1] from the Trade and Industry Committee of back-bench MPs, made important suggestions for improving COCOM.

To save delay, the Committee recommended that COCOM must object to export licences within six weeks and, to avoid accusations of unnecessary restrictions, COCOM members who object to the export should prove that damage will occur. At the moment the burden of proof is reversed and some exports of electronics can only proceed if the exporter proves that damage will not occur. In short, the Committee concluded that the Government should review the impact on trade of all the COCOM restrictions.

Finally, the Committee suggest that every year there should be a debate on the subject of restrictions on East-West trade. That will give Parliamentary authority to the COCOM restrictions, and allow MPs with electronics firms in their constituency the ability to vent their anger. At the moment, ministers have unquestioned power to delay, defer and veto and, according to several MPs, are all too ready to impose needless restrictions.

Reference

1. House of Commons Trade and Industry Committee, Second Report, Trade with Eastern Europe. HC 51, £11.30, HMSO.

Visual display units: a hazard?

Can VDUs damage your health? The answer is 'Yes' if the relevant European Community proposals are studied in Brussels[1], but 'No' when studied by a Committee of the House of Lords[2] in London.

A year ago, the European Commission (EC) proposed a Directive outlining minimum, community-wide health and safety requirements for working with a VDU. For example, they proposed that employers should monitor the employees who use VDU workstations, give information and training to staff to minimize the possible health risks, provide all VDU operatives with eye tests and pay for special spectacles when necessary. More importantly, the proposal specified minimum health requirements in relation to the safe working environment surrounding a VDU, including those covering display screens, lighting, noise and seating.

The House of Lords Committee was established to examine the Directive in detail. They heard estimates from the UK's Health and Safety Executive that the proposals would cost between £119 million and £168 million to implement and received mountains of evidence that the proposals were unnecessary and would not work.

In the end, the Committee agreed with objectors. They reported that the scientific evidence, which demonstrates the health hazards associated with VDUs, particularly in pregnancy, was too weak or inconclusive. Consequently, the Committee concluded that 'there is at present inadequate justification for an EC Directive on VDUs'.

The Committee's report did throw a bone to trades union supporters of the Directive. For example, the Committee accepted that there was widespread concern on health hazards and that VDU use may reveal previously hidden eyesight or stress problems. Most of these problems, the lords concluded, could be solved by good office management and proper staff training.

In short, those who are in favour of the Directive have to provide firm evidence that VDUs can be a risk. Without such evidence, the strong nature of the Lords' rejection and the fact that the Directive forms part of the 'social dimension' of 1992 (a taboo subject for the British Government), means that the UK's political resistance to implementing the Directive will be vigorous.

References

1. 5211/88 COM (88) 77 Proposal by the European Commission for six Council Directives on safety and health of workers at the workplace.
2. House of Lords, 22nd Report of the Select Committee on the European Communities, Visual Display Units, HL Paper 110, £8.80 from HMSO.

On The House is written by Chris Pounder.

RF COMMENTARY

European SSB broadcasting

Back in June 1947, I made the first 14MHz CW (A1A) contact with OIX-7, a 600-watt experimental station of the Finnish Broadcasting Company (Oy Yleisradio Ab). My self-built transmitter was used for testing simple directional antennas and observing the maximum usable frequency. It was then more often active on 28MHz phone (AM). At that time, the Finnish short-wave centre near Helsinki comprised OIX-1 (6120kHz, 15kW), OIX-2 (9500kHz, 10kW), OIX-4 (15 190kHz, 10kW) and OIX-5 (17 800kHz, 1kW).

In 1983 FBC began to design a new transmitter centre about 15km west of Pori, now equipped with six high-power units, including three automatic 500kW HF transmitters, a 100kW fixed-frequency HF transmitter, a 250kW HF transmitter from the original site and a 600kW MW (963kHz) transmitter.

Of particular interest are the regular experimental SSB transmissions with 1000kW peak envelope power on 15 325kHz, made daily during the German-language programmes between 1100 and 1145GMT, and targeted at Europe. Brown Boveri has developed a broadcast SSB system able to use an unmodified, high-efficiency Class C power output stage and suitable for use with the carrier reduced by 6dB or 12dB. The SSB signal amplitude information is fed to the pulse step modulator (PSM) and the phase information, in the form of phase modulation, is imposed on the output from the frequency synthesizer. Both modulations sum in the output stage producing a 1000kW PEP signal.

Jukka Vermasvuori, head of planning, has produced two technical reports on the SSB experiments: TKLA 6E/88 "Comparison between transmission modes AM and SSB using Brown Boveri 500kW SW transmitter" and TKLA 7/88 dealing with the basic problem of SSB demodulation in consumer receivers.

He stresses that the important advantage of SSB for broadcasters is the significant saving in power costs (a large HF transmitting centre can have energy costs of the order of £5000 or more an hour). With a receiver using synchronous demodulation phase-locked to an incoming signal having the carrier reduced by 6dB, the receive signal-to-noise ratio stays the same (IF bandwidth halved) and there is a 43 percent saving in energy costs compared to conventional AM. With the carrier reduced by 12dB the receiver s:n is increased by 3.5dB and the energy saving compared to conventional AM is 69 per cent. If comparison is made to AM with dynamic amplitude modulation (DAM) or dynamic carrier control (DCC) the energy saving decreases to about 45 percent. However, although the static characteristics of DCC/AM (as used at Pori) give a theoretical energy saving of about 50 percent compared with normal AM, in practice this is nearer 25 percent because of the heavy compression of programme material and the finite attack and decay times.

In Report TKLA 7/88, Vermasvuori points out that conventional envelope detection is not suitable for −12dBc reduced carrier SSB. A detector suitable for broadcast reception thus needs to be developed capable of use with four AM-based transmission modes: (1) normal AM-DSB with full carrier; (2) DBS with envelope dependent carrier (DAM or DCC); (3) SSB with −6dB carrier; and (4) SSB with −12dB carrier.

Broadcast USB transmission, for the foreseeable future, will incorporate a reduced (pilot) carrier to which a synchronous detector can be locked. A synchronous mode of detection is essential (**Fig. 1**) to prevent distortion of music due to frequency shifting. The re-inserted carrier must be within at most 5Hz of the original carrier.

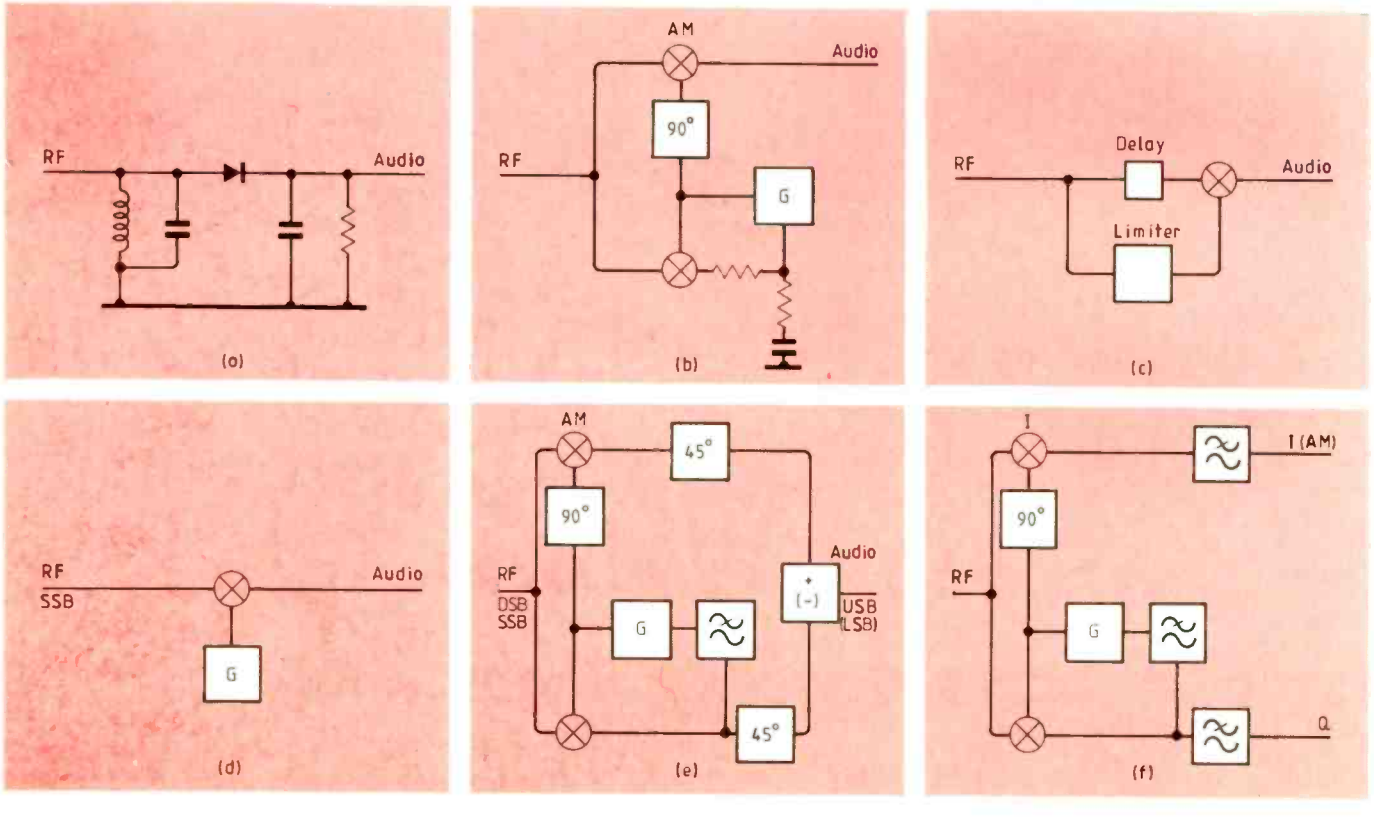


Fig.1. Six demodulators reviewed by Jukka Vermasvuori of the Finnish broadcasting company Oy Yleisradio: at (a) envelope detector; (b) synchronous detector with phase-locking; (c) quasi-synchronous detector with exalted carrier; (d) non-synchronous product detector as used for amateur SSB speech, but requiring extremely precise tuning and high oscillator stability for receiving music; (e) phasing-method demodulation, which is more suitable for integration than the filter methods; and (f) realisation of an I/Q demodulator suitable for checking and measurement applications, including measurement of DAM/DCC envelope-based modulation etc. (Report TKLA 7/88).

RF COMMENTARY

Direct digital frequency synthesis

Until recently, direct digital frequency synthesis (DDS or DDFS) was regarded as essentially suitable only for generating low frequencies, below about 100kHz. In his 1982 book "Digital PLL frequency synthesizers", Dr Ulrich L. Rohde notes that "DDS consists of generating a digital representation of the desired signal, using logic circuitry and or a digital computer, and then converting the digital representation to an analogue waveform using a digital-to-analogue converter (DAC). Recent advances in microelectronics, in particular the microprocessor, make DDS practical at frequencies ≤100kHz. Systems can be compact, low power and can provide very fine frequency resolution with virtually instantaneous switching of frequencies. DDS is finding increased application, particularly in conjunction with PLL synthesizers." DDS was then regarded as noisier than other methods, achieving adequate spectral purity only if sufficient low-pass filtering was used at the output.

Since then, progress has been rapid. Within the past year, DDS systems have begun to be incorporated in some of the Japanese-built amateur-radio HF transceivers. DDS is being increasingly recognized as a viable new option except, at present, for the lowest-cost consumer-type receiver synthesisers. DDS is now seen as capable of providing *less* phase-noise than low-cost PLL synthesisers.

In the USA a particular form of digital oscillator the Numerically Controlled Modulated Oscillator (NCMO) has been developed by, and is a registered trademark, of Digital RF Solutions Corporation. A useful series of application notes and technical articles featuring the NCMO have been written by Robert J. Zavrel advocating DDS as a means of reducing the excessive near-in phase noise of low-cost PLL synthesizers and stressing that recent advances in DAC technology, LSI controllers and memory circuits have improved DDS performance and raised the possible operating frequencies.

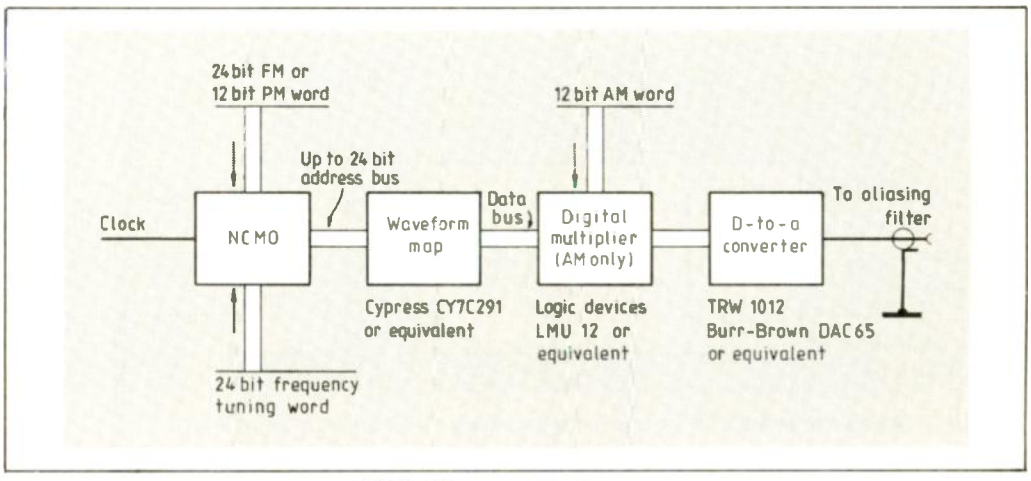


Fig.2. Four-chip DDS system using a Digital Solutions NCMO.

DDS systems, it is claimed, can be configured with close-in spurious signals 75dB below the main signal (−75dBc) with clock speeds up to 20MHz. This does not mean, however, that DDS has no current application at VHF or UHF. While the first instinct for raising output frequency from DDS is to raise the system clock frequency, Robert Zavrel in AN3002 points out that "this is not always the best technique for minimizing spurious signals, as much lower response is possible at HF (typically −75dBc) when compared with VHF DDS. The HF DDS is then up-converted to the desired operating frequency by one of several possible methods. The combination of DDS, PLL, mixer and filter technologies can offer great flexibility to the synthesizer designer. DDS should not be regarded as a direct replacement for PLLs. Rather it should be regarded as a powerful technique affording the designer with numerous new options for synthesizer design."

Zavrel has also pointed out (*Ham Radio*, October 1988) that "the DDS offers some attractive features over the analogue or PLL synthesizer. DDS is digitally controlled. Tuning is regulated by either memories or counters which, in turn, are controlled by rotary optical couplers. Unlike PLL, DDS does not use a VCO, loop filter, phase detector, or digital divider and prescaler. Waveform information is generated using digital information only. The last step uses a DAC to generate the RF signal."

The NCMO was designed by Earl McCune Jr and is a highly integrated CMOS phase accumulator with interface and modulation facilities. It uses a 24-bit phase accumulator counter and with a 24-bit tuning word gives 16 million equally-spaced discrete frequencies. The NCMO can be tuned in three ways: (1) parallel mode; (2) a strobed mode for three eight-bit words; and (3) a serial mode allowing direct connection to a rotary optical coupler to give knob tuning akin to analogue tuning.

It is claimed that a NCMO-DDS system **(Fig. 2)** can provide a phase-noise and spurious signal performance approaching that of the best free-running permeability-tuned oscillators of the 1950s, yet remains suitable for microprocessor control. Assembled NCMO-DDS boards suitable for use in HF transceivers are being offered by the firm at a price in the region of $(US)900, putting the system at present in the professional rather than amateur home-construction price range.

A detailed article on DDS and the NCMO by Robert Zavrel appears in *RF Design*, March 1988. Together with a number of data sheets, the following application notes have been published by Digital RF Solutions Corporation, 3080 Olcott Street, Suite 200D, Santa Clara, CA95054-3209, USA:

AN1007, Quadrature signal generation using direct digital synthesis by Robert J. Zavrel Jr; **AN1008**, Numeric synthesis of square waves by Earl McCune Jr; **AN3002**, HF low spurious DDS architectures, and **AN3007**, Audio to RF: a completely digital FM broadcast system by Robert J. Zavrel Jr (see below); **AN8001**, Doppler radar reference synthesizer by John S. Brewer Jr; **AN8002**, Chirp pulse signal generation by John S. Brewer Jr; and **AN8003**, Phased array radar using direct digital synthesis by Robert J. Zavrel Jr. There is also a publication by Zavrel and McCune, Low spurious techniques and measurements for DDS systems.

Direct digital stereo generator

In application note AN3007, Robert Zavrel discusses potential uses of direct digital synthesis in broadcasting, claiming that the high level of integration afforded by the numerically-controlled modulated oscillator (NCMO) could simplify the design of a completely digital stereo radio broadcast system for pilot-tone FM transmission.

He outlines a studio and digital signal processing system **(Fig.3)** using a low sampling rate (e.g. 88kHz) resulting in lower cost A/D converters and DSP FIR filters. A high clock speed (e.g. 12.8MHz) used for the stereo generator and exciter moves the alias signals well outside the exciter's SAW filter bandpass. FIR filters are used for the 15kHz low-pass filter and the

RF COMMENTARY

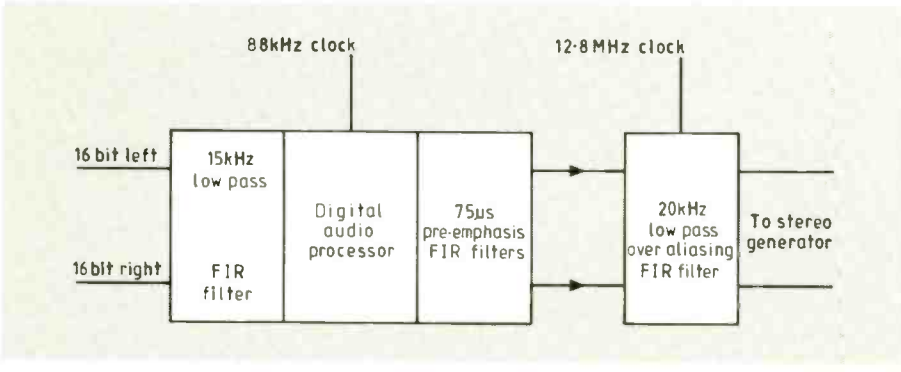


Fig.3. Studio and audio DSP system using relatively low frequency sampling.

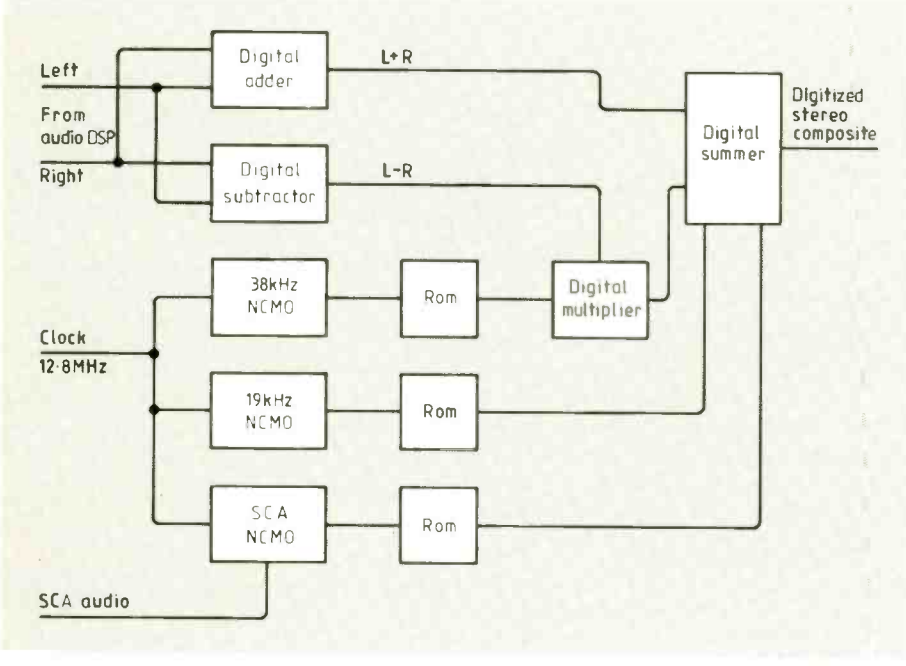


Fig.4. Direct digital stereo generator.

(American) 75μs pre-emphasis circuits.

Figure 4 shows the block diagram of a DDS stereo generator with L+R signals achieved with a digital adder and L−R with a digital subtractor. The three digitized sub-carriers for the broadcast stereo and (if required) an SCA channel are synthesized using the NCMO system, the 38kHz subcarrier being digitally modulated by the L−R signal. With a 16×16-bit four-quadrant multiplier, a double-sideband suppressed-carrier signal is generated with carrier suppression exceeding 80dB and with L−R subcarrier linearity comparable to that of a 16-bit CD player. A second NCMO-rom generates the 19kHz pilot tone. Since the 38kHz and 19kHz synthesizers are run off the same clock they are automatically phase-locked. The digitized signals are fed to a digital summer from which they emerge as a digitized FM stereo composite signal.

Mission HF in the Third World

Last year's IEE international conference on rural telecommunications drew attention to the many areas in Africa and some parts of Asia where there are virtually no conventional telecommunications facilities and few prospects of their early installation. As I mentioned in the August 1988 Radio Communications column, even a thin-line facility is better than none. At the IEE conference Dr S. A. G. Chandler (University of Warwick) described a 27MHz village network using CB transceivers powered by solar arrays, now being established in Sierra Leone. It was suggested that even a simple, largely user-maintained and operated village network, though far from "new technology", can provide a minimum but worthwhile facility.

At a rather more advanced level, a number of missions and aid agencies in developing countries have already or are planning to set up individual HF links with their base centres. This can involve the question of initiating non-technical personnel into the whys and wherefores of HF systems and choice of HF equipment.

A new publication "Where there is no telephone" gives sound advice on medium-distance HF communications links for mission and aid agencies in developing countries. Published by the Baptist Missionary Society in conjunction with the Communauté Baptiste du Fleuve Zaire (CBFZ), it has been written by John Corbett, a professional communications engineer who holds the amateur-radio callsign G3TWS and has practical experience of HF communications in Zaire.

His 100-page, low-cost booklet provides simple but sound explanations of: how radio waves travel; aerials; transceivers and power supplies; how to plan radio networks; costs and choices; how to install a system; how to operate a radio network; how to maintain a radio network; and additional facilities.

In a foreword, Jon Lewis (Area Director, Central Africa, of the Mission Aviation Fellowship) writes: "It is often difficult for the uninitiated to imagine life in the jungles of Zaire. Oh, certainly the imagination can soar to think of great rain forests, pygmy natives, river boats etc. But it is easy to take many things for granted such as good, or at least adequate, communications. Six years of living in Zaire, where virtually no telephone link exists outside the capital city of Kinshasa, has made me appreciate what a precious commodity this is. HF radio fills the crucial gap but careful attention must be paid to its installation and operation. For most of us without formal electronics education, the successful operation of an HF unit seems more akin to art than science."

This throughly practical booklet will help both technical and non-technical personnel. Costs discussed assume the use of semi-professional equipment rather than the extreme low-cost short-range CB units of the Sierra Leone village network. In the UK, the book is available from the Baptist Missionary Society, 93 Gloucester Place, London W1H 4AA for the modest cost of £2.50.

UPDATE

Micro valves on microchips

Martin Eccles

Albeit in a microelectronics form, valves came a step nearer their revival recently when a breakthrough in the production of metal cathodes was made at GEC's Hirst Research Centre in Wembley.

Microelectronics manufacturing techniques are used to produce the minute valves which have heaterless pointed cathodes with 'field-emitting' tips only a few tens of angstroms across. When negative with respect to the top of the hole in which it sits, the pointed cathode emits electrons at its tip into the field created by the potential difference; emission increases as the tip becomes sharper. The effect is caused by electron crowding at the tip akin to the corona discharge observed at high voltage point sources.

One of the main advantages of these cold-cathode field-emission valves is that they are capable of being used at very high temperatures limited only by the point at which reactions take place on the emitting tips. Up to this reaction point, their performance can improve as temperature rises, given the right construction.

It is relatively easy to produce cathodes made from silicon, but cathodes made from metals such as molybdenum and niobium, although more difficult to produce, allow a higher current density and work much better. One of the main researchers in this field, Charles Spindt of SRI International, has been experimenting with molybdenum cathodes for many years but the method he is using to make them does not lend itself readily to the production line; it involves complex thin-film deposition, and electron beam lithography.

Dr Rosemary Lee of Hirst Research leads a team that has developed a metal-tip processing sequence that is much more appropriate for the production line since it involves the use of existing semiconductor fabrication technology.

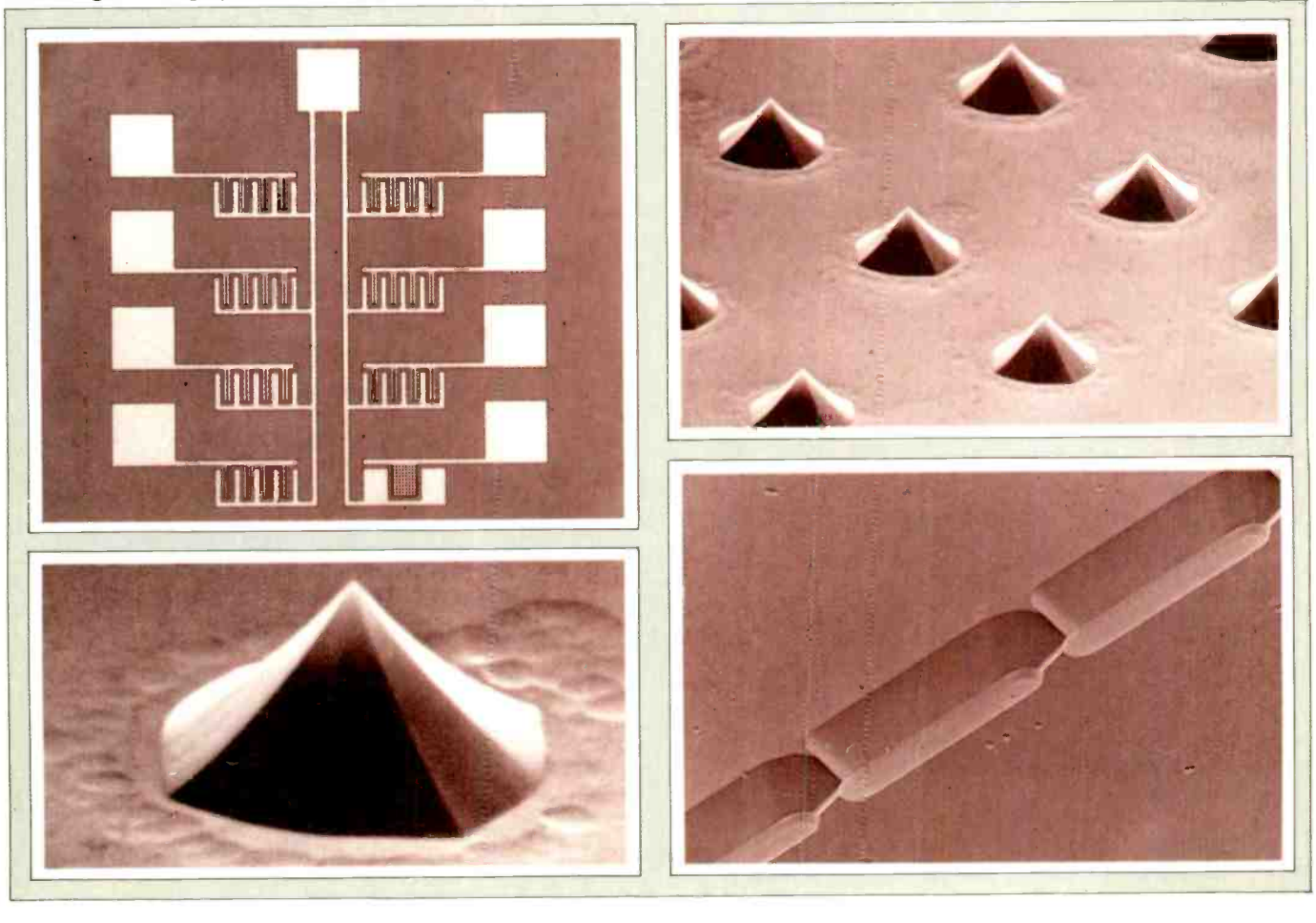
Field-emission valves are still in their early stages and they might disappear if their manufacture proves unpractical. Should they prove viable though, they might first appear as compact radiation-resistant diode arrays for transient protection in electronic circuits since such arrays are easy to make, they are fast, they can handle high peak currents and current sharing between elements in the array is very good.

Cathode technology of field-emission valves could be applied as an efficient alternative in any area where 'hot' cathodes are now used. In current thermionic valve applications, which include cathode-ray tubes and transmitting valves, heating the cathode is wasteful.

Field-emission valves could even work at temperatures as high as those in the turbine chamber of a jet engine, making possible direct rotation sensing for example. This high-temperature operation coupled with radiation resistance also suggests aerospace applications. Flat-screen displays could benefit from the technology, and should it prove possible to introduce a control grid into the current cathode/anode structure they might become everyday devices.

● Rosemary Lee of Hirst intends to give more details of this technology in our next issue.

Eight different triodes on one 2mm^2 chip, top left. With this experimental chip, produced at Hirst Laboratories, effects of emission area can be investigated; it not only has pyramid shaped emitters, but also wedge-shaped emitters like the partially-etched ones shown bottom right. Photographs from GEC Hirst Research.



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Community radio finds its voice

RICHARD LAMBLEY

Radio consultant Norman McLeod at the controls of Wireless Workshop's experimental station. To distinguish himself from Brighton's radio pirates, he liked to sign off by playing Fats Waller's recording of *Ain't Misbehaving*.

Through a shortage of enthusiasm in Whitehall, community radio stations in Britain now seem unlikely to be on the air before the middle of next year. But listeners in Brighton have already had an opportunity to sample the kind of reception quality we can expect.

An experimental station set up in the town by a local equipment manufacturer, Wireless Workshop, has been radiating a low-power VHF/FM signal under an experimental licence to a potential audience of some 25 000 spread over an area of about 4.5km^2. Transmissions from the station took place over a period of nearly three months, up to the expiry of the licence at the end of February.

The aim of the experiment was to explore some of the practical problems of local radio on a very small scale. "I'm trying to show what a neighbourhood radio service would be like", said Norman McLeod of Wireless Workshop. So compact discs, stereo and RDS were *out* and McLeod's low-tech attic studio was *in*. Audio sources during the tests were a single microphone, a cartridge machine and a turntable (the rights to transmit music were granted by the copyright protection societies, the Home Office and the DTI), all plugged into an eight-channel Alice mixer on a table. However, even the mixer had been victim of the station's keep-it-simple philosophy, and had suffered the indignity of being stripped of most of its knobs – so eliminating a temptation to twitchy fingers.

Across the room, on a "Workmate" do-it-yourselfer's bench, stood a 25W transmitter. From there, a fat coaxial feeder snaked up and away to a vertical folded dipole 20ft above roof level. According to the CCIR formula for determining antenna height, says McLeod, his is actually negative: the ground slopes upwards in nearly every direction and mostly lies above the station. Coverage is strictly confined by the terrain, a factor which community radio operators could exploit by re-using the same frequency more intensively than would be usual in BBC or ILR practice.

McLeod has been using the station to assess efficiency of coverage both in terms of listeners served per watt of radiated power, and in the distance at which frequencies can be re-used under such conditions. On both scores the low-power station appears to perform well. With an e.r.p. of 10W on 97.7MHz (a few dB are lost in the feeder) and a potential audience of one-sixth of the town's population, it delivers about 2500 listeners per watt: the BBC's nearby Whitehawk Hill relay station, with 1kW per channel, works out at only 500 per watt.

However, McLeod is far from sold on FM: he would much prefer a long or medium wave channel for community radio. "There's nothing wrong with the AM band", he says: "the problem is international mismanagement." AM's main drawbacks, narrow bandwidth and television timebase interference, need never have arisen, he believes: "The European situation is a disaster and whoever is responsible for it should be shot, and you can quote me on that."

Other work at the station has been in defining studio practice for an entirely new class of unskilled operator. "Because we're not from the IBA or BBC tradition, we can re-invent radio from the ground up", says McLeod. With his technical assistant Matt Bisson, he has set about purging studio equipment of its technical complexities. Audio leads other than (for the moment) microphone leads are of white television coaxial cable, terminated normally with quarter-inch jack plugs and driven at a standard level; mains leads are of black cable fitted with three-way IEC connectors. Level mismatches cannot occur and wrong connections are unlikely to be hazardous. Another simple idea to be explored is the possibility of doing phone-ins using a loudspeaking telephone, picked up accoustically, in place of a telephone balance unit.

Wireless Workshop specializes in supplying equipment for hospital and student radio, drawing on experience its partners gained in setting up an induction-loop station at the University of Sussex in 1976.

Today, working from its base in a former chocolate factory in Brighton, the group also provides broadcasting facilities for pop shows and other outdoor special events. For these it has a caravan equipped with a low-power MF transmitter and a 10m telescopic tower. With a capacity hat and a loading coil, this yields about 50mW of e.r.p. for 2-3W of drive and can cover a radius of about 1km. However, frequent re-tuning has proved to be necessary. "We have problems in getting a single frequency which stays with us", says McLeod. "The DTI's computer is not geared up for this." One recent example arose over a three-day show in the London docklands when he had to move off one of Wireless Workshop's usual low-power channels because BBC Radio Nottingham was due to open a relay station on the same channel a month later.

Wireless Workshop is on 0273-671928.

● The technical case for community radio was put by Norman McLeod in a *Wireless World* article in 1980 (June/July issue, pages 38-41).

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Chief Engineer
NAD Electronics Ltd.
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Modulation	— Negative
IF Vision	— 38.9MHz
IF Sound	— 32.9MHz (available 33.4MHz)
Sound Pre-Emphasis	— 50us
Ripple on IF Saw Filter	— .6dB
Output (any channel 47-860MHz)	— +6dBmV (2mV) 75 Ohm
Vision to Sound Power Ratio	— 10 to 1
Intermodulation	— Equal or less than 60dB
Spurious Harmonic Output	— −40dB (80dB if fitted with TCFL1 filter or combined via TCFL4 Combiner/Leveller

CCIR/3-1	— Specification as above but output level 60dBmV 1000mV Intermodulation 54dB
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Audio Input	— 1V rms 30K Ohms Adjustable .4 to 1.2
Vision to Sound Power Ratio	— 10 to 1
Output	— 6dBmV (2mV) 470-860MHz
Modulation	— Negative
Audio Sub-Carrier	— 6MHz or 5.5MHz
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S3 is an **Electronic Engineer's Tool-kit**. Since 1978, Softy 1 and Softy 2 have been used to develop millions of pounds' worth of new products. S3 is Softy 3.

S3 could be the only **programmer** you will ever need. S3 could also be the only **development system** you will ever need. S3 is a **set-of-tools** for designing, modifying and manufacturing products which contain Microprocessors, EPROMS, EEPROMS, RAMS, EPLDS — programmable memory and logic of all kinds.

That is what you do for a living isn't it? Or did they send you this magazine by mistake instead of Practical Beekeeping?

"I think I have all the tools I need"

Engineers have discovered lately that they are more productive in a windowing, multitasking computer environment. The PC workstation is now fashionable. Coffee-stained notebooks, boxes of tangled wire and two-legged-transistors are going out-of-style. Today you can sit down at a computer keyboard and tackle everything from design to documentation. At a keystroke you can re-assemble your source-file, download to your memory-emulator and run your program. The

"Unbelievably good, obviously designed by working engineers for working engineers"

prototype of your new product will work exactly like the real thing, except that you can set break-points, examine variables and stack, debug the code and so forth. Logic Analysers, Storage Scopes, lots of instruments these days have RS232 or IEEE interfaces, and can be controlled in another task-window, to provide insight into what's going on. S3 fits in well, needing only a single RS232 port for complete remote control. In short, if you value your time, isn't it time you bought yourself some proper equipment?

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S3 is a small computer which uses PROMS for storage like other computers use disks. A PROM in the front panel socket can be loaded as a working program or as data. S3 can make this data-memory externally available, taking the place of any 25 or 27 series PROM in your prototype. If the Flying Write Lead is connected to the microprocessor's write-line, it can emulate RAM too, by providing the WRITE input missing from PROMS. This is a real advantage over simple ROM-emulators, because variables and stack can be inspected and the target system can feedback data. Memory is permanent, in effect,

"I wouldn't dream of parting with it"

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"Why should I spend hard-earned cash?"

Presumably to help you make some more cash, a little easier.

"What's it like as a programmer?"

S3, as it comes, will program any 24/28 pin EPROM/EEPROM that goes in the socket. Of course, the manufacturers, bless their little hearts, are always bringing out PROMS which use new programming methods. But not-to-

"I'll bet you sell thousands of these"

worry, upgrading is usually a simple matter of installing the latest software which takes only a few seconds. We supply up grades at nominal cost in a PROM — or you can get 'em FREE by calling our Bulletin Board.

"It's a bit of a risk. Does it work?"

Yes! Do be careful; other makers go on about performance, yield, dire-consequences and peace-of-mind to frighten you into buying their big, expensive Prommers. Why not buy one of these on approval and compare it with S3? The

*"It beats the socks off the two ****s we've got"*

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